A COMPARATIVE STUDY OF THE GEOHYDROLOGY OF ARCHAEAN FORMATIONS AND ASSOCIATED ROCKS IN THE NORTH-WESTERN TRANSVAAL AND THE NORTH-WESTERN CAPE PROVINCE

BY

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Nothing would be done at all if a man waited till he could do it so well that no one could find fault with it

DR SAMUEL JOHNSON

ABSTRACT

An area of 4 400 km^2 in the North-western Transvaal is compared to an area of 75 000 km^2 in the North-western Cape Province with regard to geology, physiography, and hydrology. In the Transvaal the Archaean Formations range from the Swaziland System to the Dominion Reef System, with younger intrusives and a cover of Tertiary to Recent ferricrete, calcrete and soil. In the Cape Province the comparable formations are the Kheis System to the Soetlief Formation, younger intrusives and a Tertiary to Recent cover of wind-blown sand, calcrete and soil. The available literature on the geological formations and structure is reviewed. Outcrops are scarce in the Transvaal in an almost featureless tree-covered plain with ill-defined drainage, except for the two perennial rivers. In the Cape Province relief is higher and drainage better developed towards the perennial Orange River. Large portions of the Bushmanland Plateau are nevertheless, covered by sand and calcrete, without well-developed drainage. The rain falls during summer in both areas, and the average annual rainfall is 526 mm in the Transvaal, and 176 mm in the Cape Province.

In both areas the farms and villages are almost entirely dependant on ground-water supplies. The importance of geophysical methods in the selection of borehole sites is stressed, and a summary is given of the more important geological and geophysical procedures and methods in both areas. This included magnetic,

electromagnetic, and electrical resistivity methods. A summary is given of previous hydrological investigations in both areas. It was fragmentary, and only a few reports from the Cape Province could be traced.

The results of a total of nearly 1 500 boreholes drilled in Archaean Formations in the Transvaal, and nearly 3 800 boreholes drilled in these formations in the Cape Province are analysed with respect to different parameters. Boreholes are classified according to the geological formation in which they occur, and the physiographical conditions ruling in the area. In the different formations in the Transvaal the percentage of successful boreholes ranged from 30 per cent in the Dominion Reef System to 38 per cent in the Archaean Granite. In the Cape Province it ranged from 29 per cent in the Grey Gneiss to 45 per cent in the Kheis System, except for the adamellite with 6 per cent and the Soetlief lava with 90 per cent successful boreholes. In both areas certain geological and physiographical controls were determined by means of which borehole results can be improved. Analyses of geophysical data, especially apparent resistivity at the rest level, sometimes gave positive results. Depths at which water was struck, rest levels, depth of weathering, and other parameters are compared for different formations and areas.

Yields of boreholes are not high in either area, but are slightly better in the Cape Province than in the Transvaal, except for the very low rainfall areas. The wide-spread occurrence of the Grey

Gneiss was used to show increased productivity of boreholes with increase of average annual rainfall, thereby proving recharge from rainfall in this arid region. In the Cape Province a catchment area near Marydale was intensively investigated to determine the percentage of the precipitation which augmented the underground water supply. In this summer rainfall area with an average annual rainfall of 150 - 200 mm, it was nearly one per cent. In the sand-covered areas to the west, there is probably no infiltration to the ground-water reservoir, and only fossil water is pumped. In the Transvaal there is probably a balance between vegetation and precipitation so that the percentage augmenting the underground water is also very low. Still, the ground-water resources in neither area is fully developed, and drying up of boreholes is probably due to local dewatering. Criteria for better results in borehole selection are given, and safe yields for certain areas calculated.

The quality of the ground-water in the Transvaal was almost invariably suitable for human consumption, with a large percentage within the limits of the A Classification. In the Cape Province most of the supplies, some of them used for decades, were unsuitable according to accepted standards, and nearly half of the samples analysed were unsuitable for stock watering. The temperatures of ground-water corresponded in most cases to the temperature at the surface during the period of percipitation, except for deep-circulating water from fracture-zones.

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1. INTRODUCTION

1.1 GENERAL

Approximately 65 per cent of the area of the Republic of South Africa can be classified as arid or semi-arid without any surface water, and therefore dependant on ground-water for all requirements. Enslin (1964) estimated the daily use of ground-water in the Republic in 1961 to be 3×10^6 m^3, and Stander (1965) estimated it at $2{,}86 \times 10^6$ m^3.

Large portions of the dry areas are covered by granitic, gneissic and schistose rocks grouped under the name of Archaean Complex. Various other names for these oldest known rocks have been used e.g. Basements Complex or Primitive Systems. Today, as a result of geochronological research, it has been proved that some of the formations classified as Archaean, are appreciably younger than the original assumption. In several cases e.g. the Namaqualand gneisses, this is due to metamorphism and mobilisation during a younger orogenic cycle.

In this paper the statigraphic sequence illustrated in the recent issue of the Geological Map of the Republic of South Africa (1970) is followed. The only exception is that all the rocks older than the Transvaal System (± 2 300 million years) are included under the term Archaean instead of only those older than 3 000 million years.

In the areas under consideration this includes the following:

(i) Rocks associated with the Swaziland System and the Kheis System. These rocks are probably older than 3 000 M.Y. although it has not been proved by geochronological determinations. In the Cape Province the Marydale Series of the Kheis System is at least 2 900 M.Y. old.

(ii) Rocks associated with the Dominion Reef System and the Soetlief Formation, which are in all probability older than 2 600 M.Y.

(iii) The granite designated by Ag2 on the geological map, and rocks associated with it. The age of this granite was determined geochronologically as more than 2 600 M.Y. in the North-western Cape Province.

(iv) The Namaqualand Gneiss Complex and Grey Gneiss designated by Ag7 on the geological map, and rocks associated with it. Although this granite-gneiss has an age of approximately 1 100 M.Y. both Joubert (1971) and Kröner (1971) have advanced convincing arguments for the metamorphism of arkosic and argillaceous sediments of the Kheis System to produce the Namaqualand Gneiss Complex. The same origin was also suggested by Poldervaart (1950), Von Backstrom (1964), and others, for the Grey Gneiss. For these reasons and because of the similarity of the hydrological properties of Ag2, Ag7 and the granitised sediments of the Kheis System in this area, these rocks are included in this thesis. There is also no sharp boundary between Ag2 and Ag7 in the Prieska-Upington area.

According to the above arguments, the granite and gneiss previously called "Archaean Granite" (Geological Map of the Union of South Africa, 1955) would then consist almost entirely of granitised and metamorphosed sediments of the Kheis System in the North-western Cape.

1.2 LOCATION AND EXTENT OF AREAS

The areas under consideration are shown on the accompanying site plan (Fig. 1). In the Transvaal it covers an area of approximately 4 400 km^2 between south latitudes 24° and 25°, and east longitudes 26° and 28°, in the northern parts of the Rustenburg and Marico Districts. Only that part of the Archaean Complex within the boundaries of the Transvaal is discussed. According to Du Toit (1939) this comprises three-quarters of an egg-shaped occurrence, and it is bordered on the south and south-east by the Transvaal System, and on the north and north-east by the Waterberg System. On the west the area is bordered by the Marico River and the Kingdom of Botswana.

In the North-western Cape Province the Archaean rocks are found over an area of approximately 75 000 km^2 between south latitudes 25° and 32°, and east longitudes 17° and 24°. For practical purposes the area described in this thesis is confined to an area south of 28° south latitude, and south of the Orange River where it forms the boundary of South West Africa. The western boundary is taken as the Kamiesberg Mountains at approximately 18°

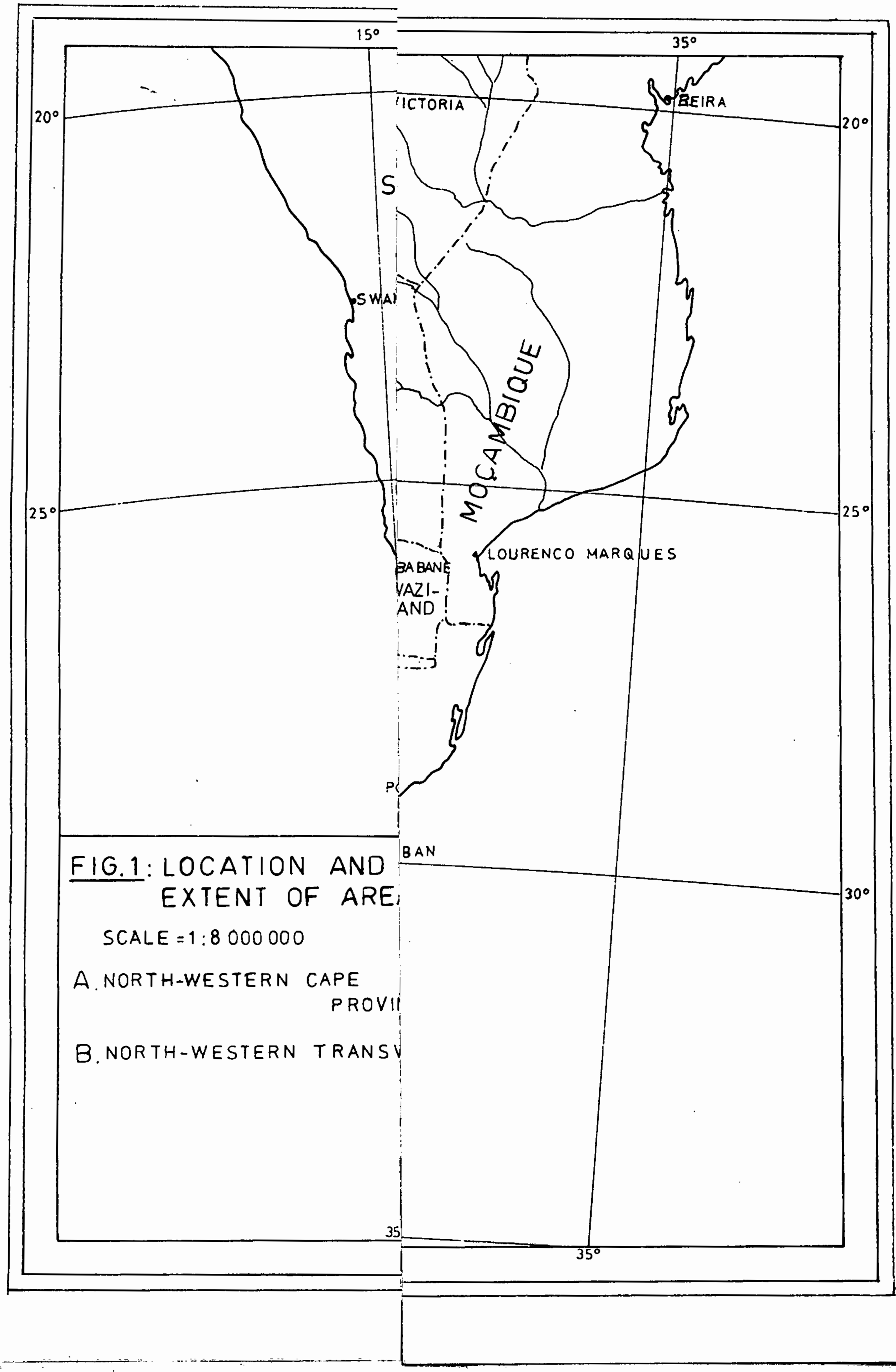


FIG.1: LOCATION AND EXTENT OF ARE

SCALE = 1:8 000 000

A. NORTH-WESTERN CAPE PROVI

B. NORTH-WESTERN TRANSV

east longitude. The southern boundary is not very well defined, being that line where the covering of Karoo System rocks (Dwyka Series) on the Archaean Formations is generally less than 30 m thick; so that boreholes are drilled into the underlying rocks above or near to the ground-water rest level or water table. This line lies between the 30th and 31st southern latitude. The eastern boundary of the area is the Doornberg Fault near Prieska, except for the occurrence of granite and the so-called "Kuip Series" near Sodium in the Britstown District. North of the Doornberg Fault the Langeberg Mountain is the boundary.

Because of the vast extent of the area, certain portions are treated in more detail, and the hydrology of the rest of the area is discussed in general terms.

1.3 PREVIOUS INVESTIGATIONS

1.3.1 GEOLOGY

1.3.1.1 TRANSVAAL

Very little has been written about the area underlain by granite and sedimentary rocks in this part of Rustenburg District, probably due to the scarcity of outcrops and lack of economic importance. Kynaston and Humphrey (1920) mapped part of the area, and commented on the scarcity of outcrops. They mentioned only the coarse-grained granite and finer-grained gneiss, with some quartz veins and pegmatites, and a few dyke-like intrusions of "diabase". The rocks now correlated with the Dominion Reef, were referred to the Ventersdorp System. Du Toit (1939) mentioned the granite, but neither Du Toit (1954) nor Haughton (1969) referred to this area, although it is shown on their geological maps. Du Toit correlated the volcanics with the Witwatersrand System, but Haughton (1969) referred to it as Ventersdorp System.

1.3.1.2 CAPE PROVINCE

Interest in this area has been active since early times. The earliest reference to the Northern Cape Area was by Andrew Geddes Bain (Anno 1797-1864) who drew up a geological map of the area between the Orange River and the south coast. In 1873 E.J.Dunn described the rocks in the Prieska area as similar to the stratified rocks of Klein Namaqualand. On his map he coloured them as Namaqualand Schists. In 1874 G.W.Stow described the 'Kheis Series in Griqualand West in his "Geological Notes on Griqualand West". Rogers and Schwarz (1900) used Stow's classification in their map and description of the area. Their 'Kheis Series consisted of quartzite and mica-schist and the granite and gneiss is described as biotite-muscovite granite and biotite gneiss.

Rogers (1906) described the t'Kuip Series and Du Toit (1908) separated the Kuip Series from the Zoetlief Formation. Truter (1947) questioned the unconformity and grouped the whole succession under the Zoetlief Formation. Further mapping in the area west of Prieska was done by Rogers (1908), Rogers and Du Toit (1909), and (1910). Schwarz (1905) correlated the Kheis Series with the basal portion of the Transvaal System and reaffirms this later (Schwarz, 1910), giving his interpretation of the course of metamorphism. Rogers (1910) considered the Kheis Series to be older than the Transvaal System and correlated it with the Kraaipan Series. He divided the Kheis Series into three units or "Beds" viz. the Marydale Beds, Kaaien Beds and Wilgenhout Drift Beds. This division has been accepted up to the present time.

Various persons investigated specific portions of, or problems in, this vast area including Gevers et al (1937), Mathias (1940), Coetzee (1941) and (1942), Söhnge and De Villiers (1946), Brink (1950), Poldervaart and Von Backström (1950), De Villiers and Sohnge (1959), Leube (1959), Jansen (1960), Von Backström (1964), Benedict et al (1964), Joubert (1971), and Von Backström and De Villiers (1972). Middlemost (1964) inferred that the Kheis rocks in the south-eastern Richtersveld consisted of impure siltstones and lavas before metamorphism and granitisation. Kröner (1971) inferred from geochemical data that the Southern Namaqualand Gneiss Complex originated from metamorphosed arkosic and intercalated argillaceous sediments, which he correlated with the Kheis System. Joubert (1971) deduced that the gneisses in the area surveyed by him are probably metamorphosed sediments of the Marydale Series of the Kheis System. The Grey Gneiss of Von Backström (1964) has been described under a variety of names by the authors mentioned above and by Visser (unpublished map), and includes various gneisses of different composition. It occurs throughout the area under consideration, bearing an intrusive, although sometimes concordant, relationship with the Kheis System. In a later publication Von Backström and De Villiers (1972) preferred the term Grey gneissic granite. They considered the Namaqualand granite-gneiss to be younger than the Grey gneissic granite.

1.3.2 HYDROLOGY

1.3.2.1 TRANSVAAL

No account of hydrological investigations in this area has been published. Short unpublished reports on the selection of borehole sites on individual farms have been prepared by geologists from time to time, but no comprehensive report exists. The only report on ground-water in this area is included in the statistical analysis by Frommurze (1937) of 234 boreholes in the Northern Rustenburg District. He found that fifty per cent of the boreholes were successful, with an average yield of 3,5 m^3/h. Water was struck between 21 and 82 m, with the highest percentage (nearly 40 per cent) between 55 and 67 m.

1.3.2.2 CAPE PROVINCE

The first geophysical investigations on farms in the Kenhardt District was done by Enslin (1944), after the previously-mentioned statistical analysis was done by Frommurze (1937). As in the Transvaal there are various unpublished reports on the selection of boreholes sites inter alia by J.J.Taljaard, B.F.Snyman and the present author. Bond (1947) published analyses of ground-water from this area. Vegter (1947) discussed the occurrence cf ground-water on certain farms in the Kenhardt District with special reference to geophysical methods, and deduced different types of aquifers. Kok (1963) discussed the occurrence of ground-water in the granitic rocks and the Kheis sediments north of the Orange River in South West Africa. He concluded that almost all of the ground-water was struck at depths shallower than 100 m. Wilke (1961) discussed ground-water in an area near Fraserburg south of the area under discussion.

1.4 OBJECT OF STUDY

Very little is known about the hydrological properties of the older formations in South Africa in the semi-arid regions. This is especially true of areas with an average annual rainfall of less than 250 mm. Smitter (1958), Van Wyk (1959), De Villiers (1961), Kok (1963), Enslin (1964) and others have investigated the occurrence of ground-water in less arid regions.

The present study compares an area of very low average annual rainfall in the North-western Cape Province with an area in the North-western Transvaal with similar geological formations and an annual rainfall of 400 to 700 mm. In the Cape Province the rainfall varies between 50 and 250 mm except for small areas on the top of the Kamiesberg and Langeberg Mountains where it exceeds 300 mm. Both areas are underlain by Archaean Formations.

The author was personally engaged in hydrological research and the practical application of ground-water investigations in the above-mentioned areas during the years 1952 to 1970; first in the North-western Transvaal, and since 1958 in the North-western Cape Province.

1.5 DEFINITION OF TERMS

Certain terms in this treatise are used in a specific sense and an explanation of them is given here.

Rest level. The level at which water stands in a borehole or well under conditions of no pumping or infiltration. This means that no cone of infiltration of depletion exists in the immediate vicinity of the borehole or well, and that the level is reasonably static for periods of 24 hours to several months or years. Changes in this level should be gradual due to recharge or drainage, and should occur over a relatively large area. The term rest level is preferred to "water table" because of the generally discontinuous nature of this level in the areas under discussion.

Resistivity. The specific resistance, usually in ohmmeter (ohm m), of the formations encountered in boreholes. This term is generally used for the apparent resistivity deduced from electrical depth probes at the ground surface.

M.S.L. or m.s.l. Mean sea level. Elevations are given in this paper as the approximate height in metres above this datum line.

Pan. Large or small depression below its surroundings in which water can accumulate. It usually has no drainage outlet and may be from one or two metres to 30 m or more below the general level of its surroundings, and have steep or gently sloping rims.

Vloer. Large and shallow depression, usually devoid of vegetation or with very sparse vegetation. The vloers occur along river courses and are sometimes flooded for brief periods after heavy rain and inundation by the rivers. It is generally at approximately the same elevation as the riverbed.

Turf or black turf. A dark-coloured fine-grained very clayey soil, practically impervious to water. Usually associated with basic rock-types.

Laagte. This Afrikaans term, now generally accepted in English, is a better term than "valley" for the wide, shallow drainage trough of a short ephemeral stream, which often flows only once in two to five years.

Rainfall Normal. The mean of the weighted and calculated rainfall over a continuous period of at least 30 years reduced to a yearly average. This is regarded as a true normal. For shorter periods or discontinuous records the mean is described as "average rainfall" by the Weather Bureau (1955).

Yield (of a borehole). The yield in m^3/h as tested for six hours or longer by a mechanical pump, usually immediately after completion of the borehole. The yield of a weak borehole is sometimes tested by bailer for one to two hours. Where no test was done the yield is determined by the maximum capacity of the pumping installation.

Successful Borehole. The minimum yield of a successful borehole is regarded as 100 g.p.h. in Southern Africa. This is equivalent to 0,45 m^3/h, and all yields given in gallons per hour, litres per second, kilolitres per hour, etc. have been reworked to m^3/h.

Economic Yield. Although a borehole yielding 0,45 m^3/h is regarded as successful in Southern Africa, the minimum yield which can be economically utilised depends on several factors. In the North-western Transvaal, where power-heads and engines have to be used to pump water for the watering of large stock, 1,36 m^3/h is regarded as the minimum economic yield. In the North-western Cape Province, where wind-mills are used to water small stock, yields of 0,3 m^3/h have been used successfully.

Depth. In all cases where depth to ground-water rest level, depth at which water was struck, depth of weathering, depth of borehole, etc. is mentioned in the text or in illustrations, it refers to the depth that was measured at the position of the borehole from the ground surface vertically downwards.

Fracture-zone. Zones of faulting, shearing, fracturing, or jointing which are prominent hydrologically and sometimes topographically. Secondary quartz is invariably present, breccia and mylonite usually, and epidote, calcite, fluorspar, etc. sometimes. It must be recognisable as a linear structure from the surface.

Poort. Narrow opening or break in a ridge or chain of hills, through which the drainage from a catchment area takes place. It is always narrow compared to the width of the upstream valley.

p.p.m. Parts per million of the ions dissolved in ground-water, as determined by analyses.

<u>T.D.S.</u> Total dissolved solids in ground-water as determined by analyses, usually given in p.p.m.

2. PHYSIOGRAPHY

2.1 RELIEF

Relief plays a very important role in the hydrological cycle, especially in arid and semi-arid regions with summer rainfall. Because rain usually falls in sudden sharp showers with high intensity, and the surface percolation is controlled to an appreciable extent by the aerial relief.

2.1.1 TRANSVAAL

The area lies to the north of the Witfontein Ridge and is traversed by the Marico and Crocodile Rivers. It lies at an altitude of 885 to 1 040 m above m.s.l. and is practically flat with gentle slopes towards the north-west and north-east. The slope from Stratford 787 to Cumberland 779 is 1:346 ; and from Brussels 487 to Cumberland 779 it is 1:383. On the granite and gneiss between Engeland 862 and Cumberland 779 the slope is even flatter viz. 1:566. The area is an almost completely featureless plain, and is covered by park-like growths of indigenous trees and shrubs with a grass cover between the trees. Valleys are shallow and wide. The Marico and Crocodile Rivers have low gradients and are incised from 2 to 5 m below their banks. The gradient along the Marico River between Maricodraai 74 and the confluence with the Crocodile River is 1:900.

A few low kopjes on South Brabant 248 and Krugerspan 804 do not rise more than 30 m above their surroundings. Near the Crocodile River a more undulating stretch of country provides local relief of a few metres. According to King (1967) this area is part of the post-African cycle with an advanced stage of planation.

2.1.2 CAPE PROVINCE

Elevations in this area vary between less than 200 m at Goodhouse and 1 708 m in the Kamiesberg. Mabbutt (1955) distinguished the following topographical features:

(a) The Namaqua Highlands reaching an elevation of 1 150 to 1 190 m above m.s.l. in the Kamiesberg Mountains and Agenysberge, and rising to 1 250 m in the Doornberge. It was probably formed during the Cretaceous and forms part of the Gondwana Cycle described by King (1967).

(b) The Bushmanland Plateau was cut into these highlands to an elevation of 976 m. This plain was at an advanced stage of evolution during the middle of the Tertiary. The crustal warping of that time caused widespread disruption and reversal of drainage in Bushmanland, resulting in the formation of large pans and vloers. Today the valleys are wide and shallow with very low gradients so that run-off from the occasional storms seldom reach the bigger rivers.

This plateau was probably formed during the African Cycle (King, 1967). Dinosaur fossils found at a depth of 34 m in a well on Kangnas (Gevers et al, 1937) are of late Cretaceous age and probably an intermediate stage between the Gondwana and African Cycles.

Conglomerate and grit lying on the edge of the Bushmanland Plateau on Platbakkies, Banke and Bokseput between Loeriesfontein and Springbok, were silicified and ferruginised, probably at the onset of a drier climate.

(c) As a result of rejuvenation two subcycles were formed:

(i) A subcycle at 793 m has a restricted area in the lower reaches of the Koa Valley, which is a drainage feature subsequent on the warped Bushmanland Plateau.

(ii) At 610 m another subcycle developed along the Orange River and the Molopo River. This extended north and south of the Orange River to the west of the area under discussion and included the Neint Nababeep Plateau. These subcycles are tentatively called the Victoria Falls Cycle by Mabbutt (1955). This post-African cycle (King, 1967) is observed along the Vaal and Orange Rivers outside the eastern border of the area under discussion.

(d) Major rejuvenation now occurred, which is illustrated in the gorge of the Aughrabies Falls, the lower reaches of the Henkhries Valley, the Uranoop River, and other narrow incised tributary gorges to the Orange River. For approximately 30 km from the river relief is high and the topography young. This rejuvenation graded the rivers down to 457 m. According to King (1967) this rejuvenation occurred during the early Quarternary.

Probably most of the wind-blown sand in the area is of this age. In the western part of Namaqualand inselberge of granite, sometimes topped by quartzite, rise out of the sand-covered plain.

The characteristics of the regional drainage seem to indicate moist conditions at least until the mid-Tertiary or later, probably the Pliocene, when the 793 m level was formed. This is the last period of broad open valleys, and the beginning of steeply-incised gorges. The meanders in them owe their preservation to rapid down-cutting, hardness of the rock, and the aridity of the climate. The onset of calcification and the formation of calcrete at the surface of the Bushmanland Plateau, took place no later than early Pliocene times. There is strong evidence that the Orange River Valley predated deposition of the Dwyka Series of the Karoo System in its lower reaches between Goodhouse and Oranjemund, according to Haughton and Frommurze (1936), and Von Backström and De Villiers (1972). This means that the Orange river Valley must have been in existence when the Namaqua Highlands were formed.

2.2 DRAINAGE

2.2.1 TRANSVAAL

Valleys are wide and shallow and sometimes ill-defined, and shallow pans or depressions are numerous. The only perennial rivers, the Marico and Crocodile, as well as some of the larger tributary valleys, have well-defined channels which is incised 1 to 5 m below the surroundings. Drainage is generally towards the north-west, north and north-east. The Marico and Crocodile rivers which rise on the edge of the Highveld to the south, have flowing water for six to eight months per year throughout their lengths, and pools and seepage flow only after relatively heavy showers. The pans are shallow depressions of 0,2 to 2,0 hectares in extent, usually surrounded by a thick growth of trees or bush. The surfaces of pans consist of ferricrete, limestone, or more generally of black turf or a light-coloured clayey soil called "brack". A line of pans usually indicates a previous drainage channel.

Very few dams can be built due to the preponderance of deep red loamy soil in the valleys, the low rainfall, the low gradients and the absence of well-defined channels. The few existing dams were built in the larger tributaries on clayey black turf.

2.2.2 CAPE PROVINCE

Only one perennial river traverses this area viz. the Orange River which rises in the Lesotho Highlands and drains the whole area from east to west towards the Atlantic Ocean. The Vaal-Orange is a mature river system flowing south-west from the confluence of the Vaal and Orange Rivers towards Prieska, and then north-west until it cuts through the Kaaien Series east of Upington. From Upington it flows WSW to Kakamas and then WNW past the Aughrabies Falls to the boundary of South West Africa. There it once more changes direction to the WSW until it reaches the vicinity of Pella, from where it runs in a general westerly direction up to the Richtersveld, where it makes a large horse-shoe towards the north before flowing into the Atlantic Ocean at Oranjemund. On the eastern boundary of the area the Orange River flows at an elevation of 885 m above m.s.l., and just above the Aughrabies Falls at 625 m. The average gradient over this length is 0,85 m/km. According to Von Backström (1964) the average gradient is 1,55 m/km between Upington and Rhenosterkop Island. Between the eastern boundary of the area and Upington the gradient is only 0,59 m/km, and between the confluence of the Vaal and Orange Rivers and Prieska it is 0,19 m/km. At Aughrabies Falls the river plunges downwards for 140 m, and for the next 160 km the gradient is approximately 1,19 m/km. West of that it is again lower. According to Von Backström and De Villiers (1972) the gradients is 0,61 m/km between the mouth of the Coboop River near Onseepkans and Modderdrift, west of Vioolsdrift. The average gradient between Upington and a point 16 km WSW of Onseepkans (approximately 280 km) is therefore 1,74 m/km, and west and east of it 0,61 and 0,59 m/km respectively. These changes in slope are due to the crustal warping during the African Cycle and the formation of the Bushmanland Plateau, and to the major rejuvenation after the Victoria Falls Cycle of Mabbutt (1955).

The main tributaries of the Orange River are the following:

(a) The Hartebeest River WSW of Kakamas. This river rises in the Nieuweveldt Escarpment as the Sak river, the Riet River, the Rhenoster River and the Fish River, but after the confluence with the Carnarvon Leegte (or Olifantsvlei River) it is called the Hartebeest River and flows north to Kenhardt and then north-west to the Orange River. It is an intermittent river with low gradient and large vloers. It becomes brack soon after flood-flow ceases, and it yields salt water from bank storage below Kenhardt, sometimes within days after floods.

(b) The vast areas drained by the Molopo, Kuruman, Auob and Nossob Rivers have a low rainfall and lie principally in the sandy Kalahari desert. Sand dunes stop floods in these rivers and the waters do no longer reach the Orange River. In the lower reaches of the old Molopo Valley warm and hot springs issue.

(c) The Fish River, draining the plateau area in South West Africa as far north as Rehoboth, is an intermittent river with occasional devastating floods. It may flow for months at a time, but the water soon becomes brack, sometimes within a few weeks after floods. Hot and scalding springs issue in the Fish River Valley, of which the most important is at Ai-ais.

(d) The Koa Valley, which becomes the Henkhries Valley near the Orange River, is a drowned valley filled with up to 200 m of sand and unconsolidated sediments. It must have drained a large area to the south of the Orange River, but at present no water flows in it. In the Henkhries Valley where the surface falls rapidly towards the river, several weak springs issue, but they yield brack water. The tributaries flow in a general northward or southward direction towards the Orange River, except for the Koa Valley which is an older drainage feature, formed before the major rejuvenation at the end of the Victoria Falls Cycle.

In the Orange River a hot spring (temp. 45°C) issues on the farm Warmbad Noord between the Aughrabies Falls and Onseepkans.

South of the Orange River where the Archaean Formations are covered by a thin layer of horizontal Karoo sediments, large pans and vloers are numerous e.g. Verneukpan, Commissioner Salt Pan and Grootvloer. Numerous other pans of different sizes have deposits of salt and gypsum. North of Upington large salt pans were formed between dunes. Small and shallow pans or depressions are ubiquitous over the whole area because of the very low gradients, even where there is no covering of Karoo sediments. They are especially numerous on the Bushmanland Plateau.

2.3 VEGETATION

2.3.1 TRANSVAAL

According to Acocks (1953) the following veld types are found in this area: Turf Thornveld, Sour Bushveld, Arid Sweet Bushveld, Shrub Bushveld, and Mixed Bushveld. This is illustrated in Fig. 2.

The whole area is thickly covered by trees and bush, of which an appreciable percentage is deciduous. Over the greater part of the area the trees are large and well-spaced, providing a park-like landscape with a good grass cover. It provides excellent

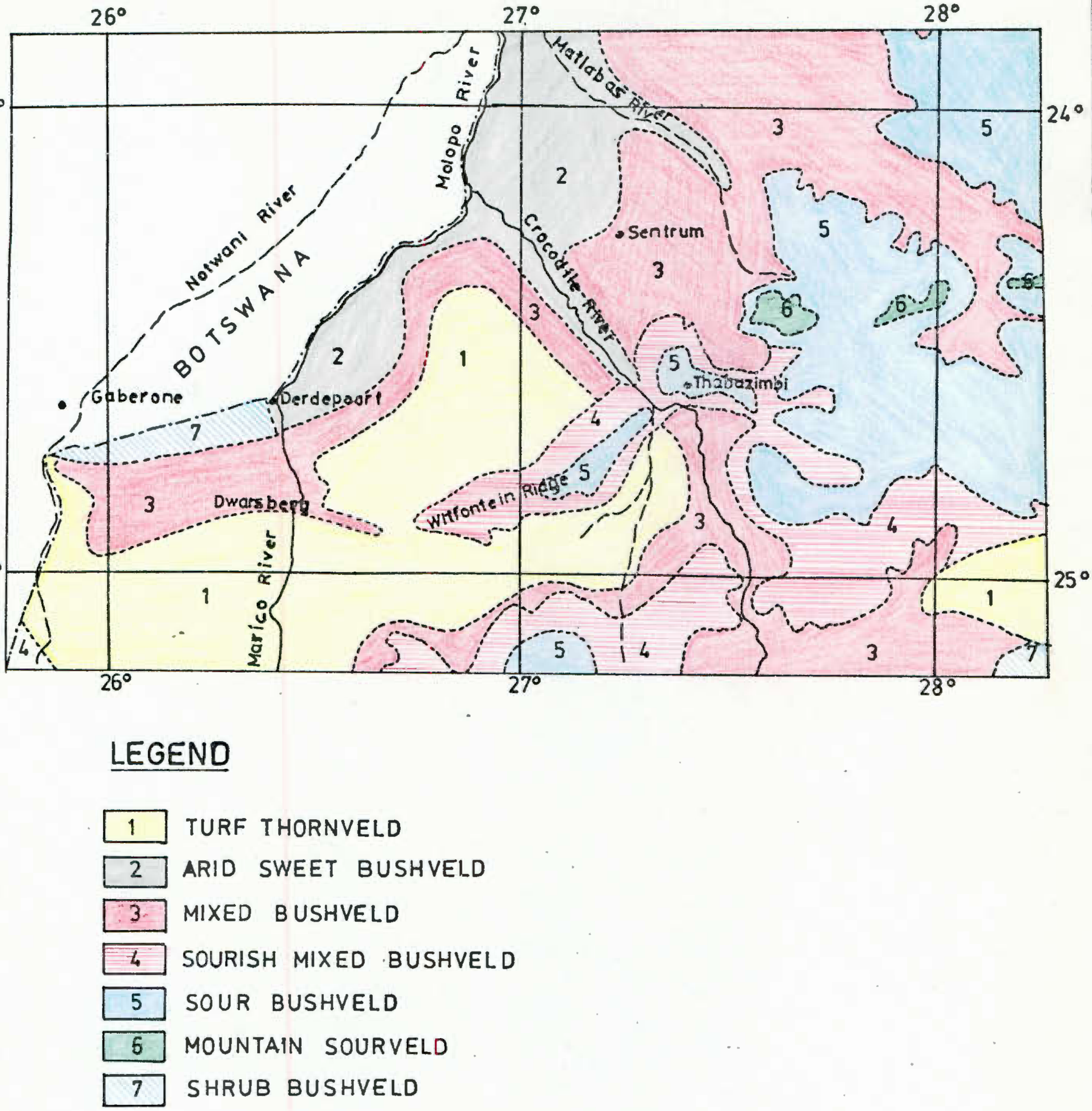


FIG. 2 – VELD TYPES IN NORTH-WESTERN TRANSVAAL (AFTER J.P.H. ACOCKS)

SCALE = 1:1 500 000

pasturage for cattle. Along drainage lines, next to pans, and on turf soil, dense bush are found between the trees. Low-growing shrub-acacias, the so-called "mashouka" (acacia grandicornuta) and grewia-types sometimes form impenetrable growths, to the exclusion of grass, while for example on Merinowalk 242 a large part of the farm is practically treeless.

Although the weathering is deep, the surface has very low relief and the weathered material is mostly in situ. The vegetation therefore gives an indication of the underlying subsoil and the geological formations from which it was derived:

(i) Although sometimes found on other types of soil, the following trees prefer the low-lying turf soil and dark-coloured loamy soil associated with the Swaziland System - sweet thorn (acacia karroo), knoppiesdoring (acacia nigrescens), haak-en-steek (acacia heterocantha), snuifpeul (acacia arabica), swarthaak (acacia detinens), kaffer-wag-'n-bietjie (acacia caffra), brosdoring (acacia robusta), and wag-'n-bietjie (ziziphus mucronata). Along the perennial rivers the wild fig (ficus sycamorus) grows.

(ii) At the contact between different formations e.g. along some of the drainage lines and along the perimeters of pans, a more shrublike vegetation grows. Typical of the group is ghwarrie (euclea divinorum), sekelbos (dichrostachys nyassana), rosyntjiebos (grewia flavescens), kruisbessie (grewia occidentalis), and other grewia-types.

(iii) On sandy soil and sandy loam which are derived from arenaceous sediments and the fine-grained or micaceous granite, the following trees are found: marula (sclerocarya caffra), hardekool (combretum imberdi), both of which prefer deep soil, raasblaar (combretum zeyheri), rooibos (combretum apiculatum), tambooti (spirostachys africanus) which prefer slightly more loamy soil and therefore are often found near contacts with the Swaziland System, witgatboom (boscia albitrunca), wild olive (olea africana) which only grows along drainage lines, and wild plum (ximenia caffra).

(iv) Soil consisting entirely of sand and humus with practically no loam, and which is often ferruginous, sometimes with a layer of ferricrete at the surface, is found only on the coarse-grained light-coloured granite. The typical vegetation is wild syringa (burkea africana), wild quince (pterocarpus rotundifolia), vaalboom or sandgeelhout (terminalia sericea) and several of the schotia-types, inter alia the huilboerboon (schotia brachypetala).

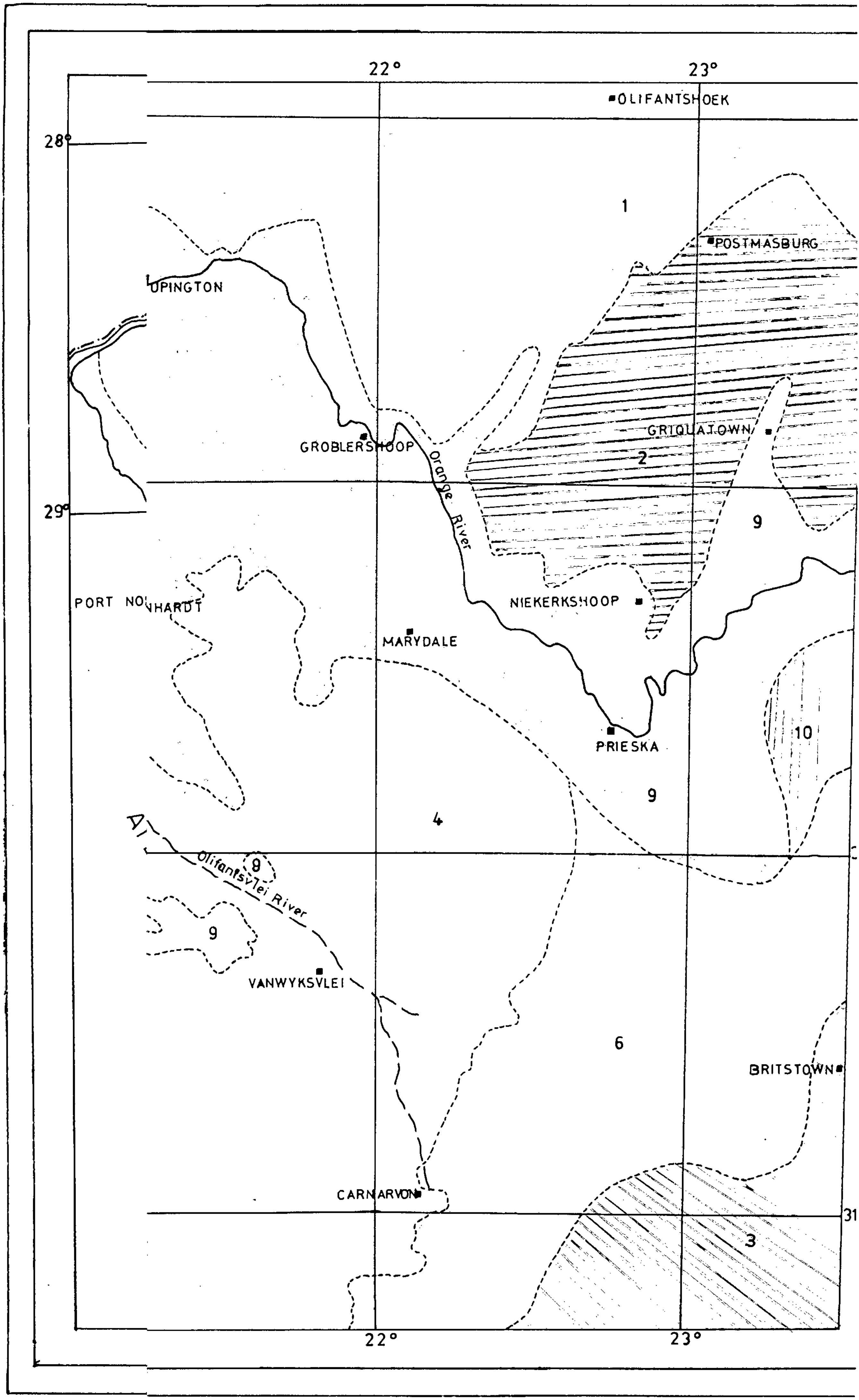
The above distinctions are not sharp and different groups might be found intergrowing in the same area. Used on conjunction with other parameters this classification of the vegetation can, however, be useful in unravelling the distribution of the geological formations in the areas where no outcrops are found.

2.3.2 CAPE PROVINCE

According to Acocks (1953) the following veld types are found in this area, the distribution of which is shown in Fig. 3:

Orange River Thornveld north of the Orange River;

Orange River Broken Veld from Prieska to the South West African border on both sides of the Orange River;



22°
23°
OLIFANTSHOEK
28°
1
POSTMASBURG
UPINGTON
GROBLERSHOOP
Orange River
GRIQUATOWN
2
29°
9
PORT NOLLOTH
NIEKERKSHOOP
MARYDALE
10
PRIESKA
9
4
8
Olifantsvlei River
9
VANWYKSVLEI
6
BRITSTOWN
CARNARVON
31
3
22°
23°

Namaqualand Brolen Veld further to the west and along the Kamiesberg Range;

Arid Karoo and Desert False Grassveld in the southern and western portions;

False Arid Karoo in the south-west;

Western Mountain Karoo round Loeriesfontein;

Succulent Karoo in the Nuwerus Area;

False Succulent Karoo south and south-west of Pofadder;

A small area of Mountain Rhenosterbosveld on the top of the Kamiesberg.

In contrast to the Transvaal the vegetation is mostly xerophytic, although a large variety of grasses and annuals flourish for a short time after good rain. Succulents are found over the whole area. Especially prominent are several varieties of aloes, of which kokerboom (aloe dichotoma) grow in thousands along hill-slopes throughout the area. In the south-west mesembrianthemums are prominent.

The cover of trees and shrubs is sparse. Trees are usually found only along watercourses or on the flanks of mountains. Swarthaak (acacia detinens) is found in the hills and the foothills of mountains, and on calcrete; sweet thorn (acacia karroo) along rivers; camelthorn (acacia giraffe) and vaalkameel (acacia haematoxylon) along dry sandy courses with deep soil or between the sand dunes of the Kalahari; haak-en-steek (acacia heteracantha) only near the Orange River. Karee (rhus lancea) and suurkaree (rhus pyroides) are hardy trees found along large and small laagtes throughout the area. The witgatboom (boschia albitrunca) is found on shallow stony soil, often far from watercourses. Wag-'n-bietjie (zizphus mucronata) and wild olive (olea africana) are found only along watercourses, usually where the ground-water rest level is shallow.

The largest part of the permanent covering in this area consist of low-growing shrubs which form the staple diet of the sheep and goats on the farms. Besides the larger driedoring (rhigozum trichotonum) which covers large areas of the plains and gentle slopes, granaatbos (rhigozum obovatum) and klapperbos occurring along the slopes of ridges, and the taaibos (rhus-varieties) along drainage lines, there is a large variety of smaller and larger aromatic shrubs much favoured by sheep and goats. They are locally known as wolfdoring (phaeoptilum spinosum), brosdoring (phaeoptilum-variety), kriedorings (lyceum-varieties), karoobos (pentzia-varieties), kapokbos (eriocephalus glabea), beesganna (salsola tuberculata), rooilootganna (salsola aphylla), koolganna (salsola zeyheri), melkbos (euphorbia-varieties), and others. These shrubs are usually found near outcrops, in the mountainous or broken country, or in the eastern hardeveld where calcrete occurs at or near the surface. On the sand-covered areas the growth sometimes consists exclusively of grasses, mostly aristida-varieties and of "winteropslag", which consists of a large variety of annuals.

Along larger watercourses the ghwarrie (euclea undulata) and several grewia-varieties may be found. Along the Orange River groves of Cape willow (salix capensis) are found, and along its lower reaches the shady Orange River Ebony (euclea pseudo-ebenus). On quartzitic ridges the very poisonous naboom (euphorbia ingens) grows, and west of Kakamas the strange halfmens (pachypodium namaquanum) on low ridges.

2.4 CLIMATE

2.4.1 RAINFALL

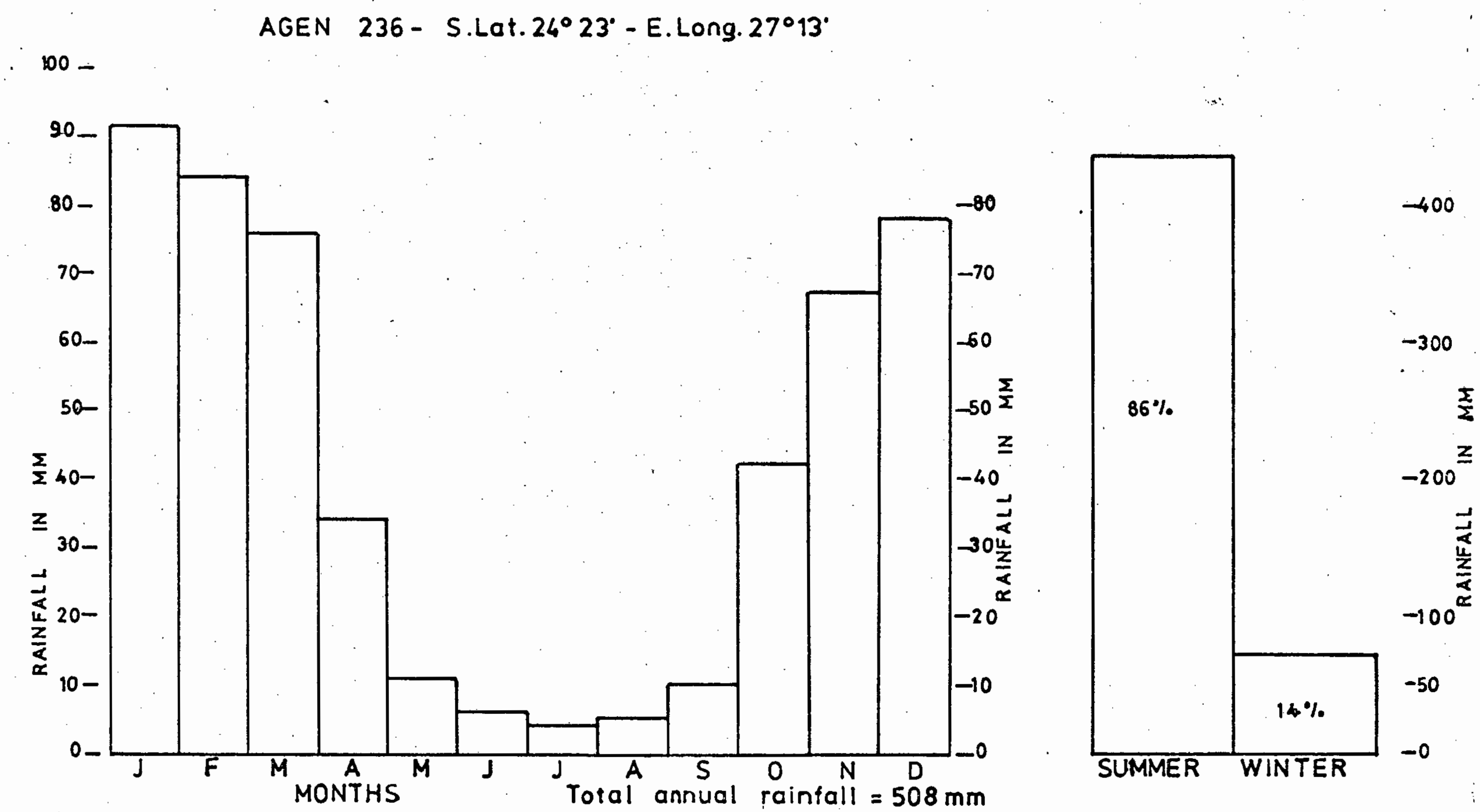
Most of the following details were obtained from Climate of South Africa (1955 to 1960).

2.4.1.1 TRANSVAAL

The average annual rainfall at twelve gauging stations scattered over the area was 502 mm for an average period of fourteen years. During the seven summer months between October and April 93 per cent of the mean annual precipitation was measured, and 78 per cent during the five months November to March. The average maximum annual rainfall is 760 mm and the average minimum 277 mm. If ten gauging stations on the periphery of the area are included, the average annual precipitation over an average period of eighteen years is 526 mm, with an average maximum of 809 mm, and minimum of 293 mm. Individual averages vary between 671 and 417 mm, individual maxima between 1 047 and 629 mm, and individual minima between 446 and 160 mm. Years with high precipitation over the whole area were 1939, 1943 and 1944. 1941 and 1945 were dry years, and 1935 was outstandingly dry. Rainfall normals calculated from 30 years of unbroken records, were recorded for only one gauging station within the area, and it corresponds very well with the results from the twelve stations given above, viz. a mean annual precipitation of 508 mm. During the half-year October to March 86 per cent of this precipitation was recorded. According to the normals for three gauging stations between 5 and 20 km from the area on the south side the annual precipitation was an average of 595 mm. Normals of two gauging stations to the north and north-east showed an average of 488 mm per annum. The distribution of the summer and winter rainfall is however exactly the same. A histogram of monthly rainfall is given in Fig. 4.

The rainfall diminishes towards the north-west, and reaches a peak in the high ground towards the south-east of the area in the vicinity of Thabazimbi, Sterkfontein and Apiesrivierpoort. The isohyets (with 50 mm interval) of the area are shown in Fig. 5. This figure is based on available rainfall statistics (Climate of South Africa, 1955). The statistics of the gauging stations within the area are given in Table I.

The rainfall does not deviate much from the average. The mean deviation as a percentage of the average annual rainfall is less than 20 per cent in this area. This means that the reliability of the annual precipitation is more than 80 per cent of the average. (Climate of South Africa, 1960).



F IG. 4 - AVERAGE MONTHLY AND SEASONAL RAINFALL, N.W. TRANSVAAL, over a period of 30 years.

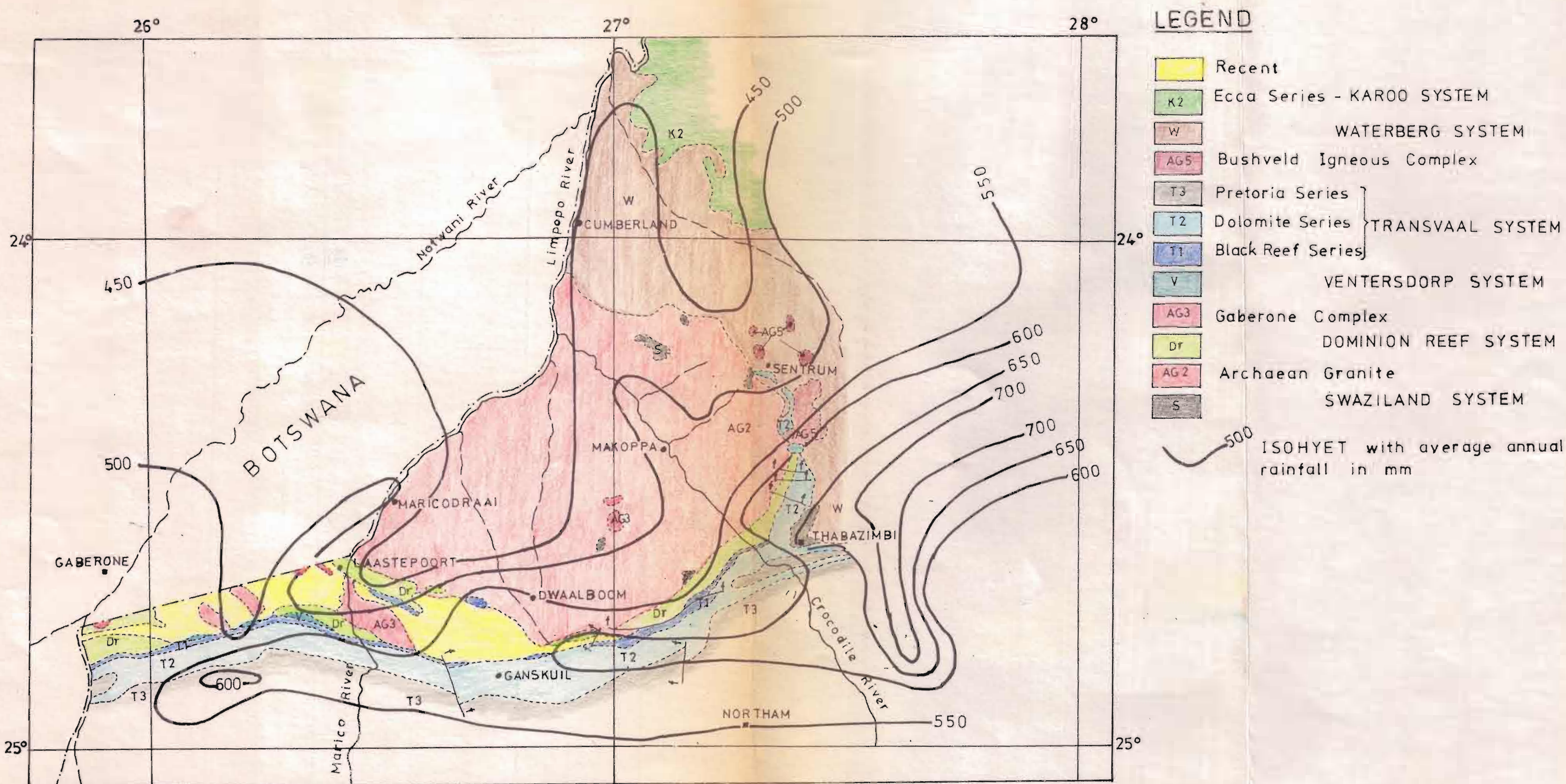


FIG.5 - GEOLOGY AND RAINFALL, N.W. TRANSVAAL
Scale = 1 : 1 000 000

TABLE I. AVERAGE RAINFALL IN THE NORTH-WESTERN TRANSVAAL
(AFTER CLIMATE OF SOUTH AFRICA, WEATHER BUREAU)

Name	Number	Latitude	Longitude	Elevation in m	Period years	Annual Rainfall				
						Average mm	Maximum mm	Year	Minimum mm	Year
Vleeschfontein	585/528	24°48'	26°18'	1 109	35	589	974	1944	352	1926
Kameelhoek	585/879	24°39'	26°30'	1 006	10	417	638	1937	205	1938
Stellenbosch	586/138	24°48'	26°35'	1 027	21	542	862	1943	333	1945
Brussels	586/341	24°41'	26°42'	1 067	10	565	850	1944	282	1945
Ganskuil	586/441	24°51'	26°45'	1 089	42	573	926	1939	342	1938
Engeland	586/545	24°35'	26°49'	975	21	432	629	1943	160	1935
Uitenhage	586/789	24°39'	26°57'	995	16	513	708	1939	230	1935
Middelkop	587/139	24°49'	27°05'	1 097	26	634	1 047	1943	396	1935
Buffelsdoorns	587/214	24°34'	27°08'	945	12	505	870	1944	230	1935
Tierkloof	587/405	24°45'	27°14'	1 097	18	582	761	1943	311	1935
Prerus	587/483	24°33'	27°17'	1 067	9	608	818	1944	446	1945
Mohani	587/668	24°38'	27°23'	899	29	576	908	1921	272	1935
Thabazimbi	587/697	24°37'	27°24'	1 026	14	671	1 044	1939	443	1941
Maricodraai	629/30	24°30'	26°31'	914	7	510	792	1943	385	1948
Tweeriviere	629/702	24°12'	26°54'	853	25	447	687	1939	259	1935
Parys 208	630/78	24°18'	27°03'	914	8	528	725	1939	329	1941
Agen	630/383	24°23'	27°13'	917	27	509	875	1940	281	1935
Somerset North	630/391	24°01'	27°14'	900	9	421	707	1936	220	1941
Brightwood	630/408	24°18'	27°14'	998	12	503	778	1939	267	1932
Groenvlei	630/556	24°16'	27°19'	998	16	488	748	1944	250	1935
Groenrivier	630/826	24°16'	27°28'	975	25	511	717	1944	279	1926
Cumberland	672/748	23°58'	26°55'	853	40	452	743	1936	174	1935
			Average		18	562	809		293	

FIG. 6 - GEOLOGY AND RAINFALL, N.W. CAPE PROVINCE.

Scale = 1:1 000 000

2.4.1.2 CAPE PROVINCE

2.4.1.2.1 NORMALS

The rainfall throughout this area is very much lower than in the Transvaal. An average of 53 mm per annum was recorded over thirteen years at Soutputs between Pofadder and Springbok. The highest average annual rainfall was measured at Leliefontein in the Kamiesberg viz. 343 mm over a period of 48 years, and at Good Hope in the Boesmansberge south-west of Prieska viz. 234 mm over twelve years. In contrast the minimum average annual rainfall in the Transvaal area was 417 mm and the maximum average 671 mm. Except for the coastal areas west of, and including, the Kamiesberge, most of the rain falls during summer. The division between summer and winter rainfall is , however, not as sharp as in the Transvaal. From Brandvlei to Vosburg between 63 and 67 per cent is summer and 35 per cent winter rainfall. From Pella eastwards to Prieska the percentage of summer rainfall increases from 65 per cent to 72 per cent. From Kakamas northwards to Swartmodder the summer rainfall also increases, from 68 to 75 per cent. Isohyets with 25 mm and 50 mm intervals are shown in Fig. 6, which is adapted from Climate of South Africa (1955). Histograms of the annual distribution of rainfall are given in Fig. 7. It can be seen from this figure that the Bushmanland Plateau receives very little rain, and the same is true of the Orange River Valley west of the Aughrabies Falls.

In summer the rain usually falls as sudden thunderstorms of short

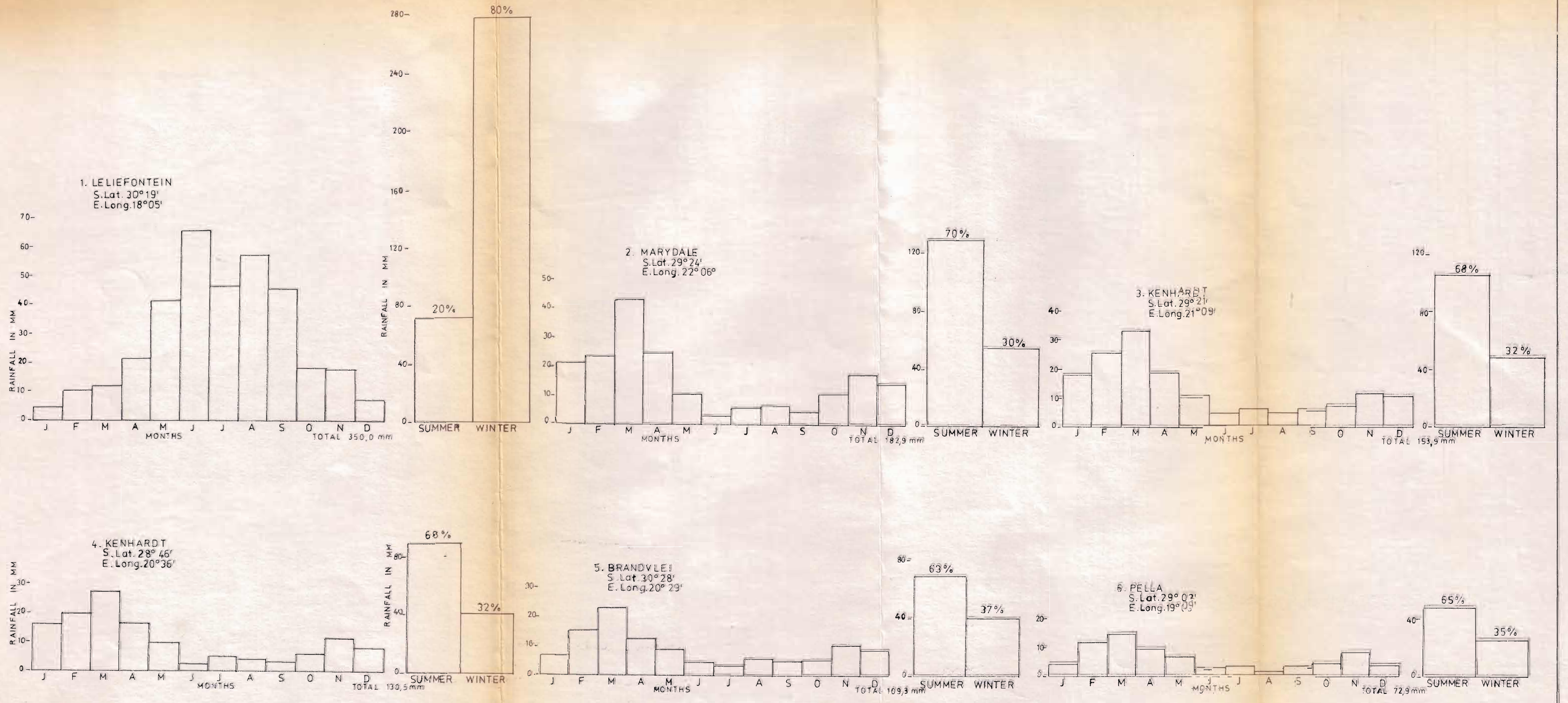


FIG. 7 - HISTOGRAMS OF AVERAGE MONTHLY AND SEASONAL RAINFALL, N.W. CAPE PROVINCE

duration. In the sand-covered areas this rainfall is absorbed immediately, but in the hardeveld there is a relatively high run-off towards watercourses. Due to the generally low gradients velocity is low, and the water is easily impounded behind low erosion embankments or dam-walls.

The bulk of the rain falls during February to April at the end of summer and during autumn. The fact that the season of rapid growth is then past means that transpiration is not as high as during the more erratic rainfall of the early summer (October - November), and some of the rainfall can percolate through to the ground-water reservoir. Due to low humidity and high temperature variations evaporation is very high, averaging for example 280 cm per annum from a standard evaporation tank at Kakamas, during thirteen seasons (Rainfall Map, Department of Irrigation, 1945). In the sand-covered areas there is probably a balance between precipitation and evapo-transpiration so that no water reaches the ground-water reservoir (Martin, 1961). Some rainfall normals are given in Table II. The bulk of the gauging stations have been observed for more than 30 years.

2.4.1.2.2 DEVIATIONS FROM NORMAL

This semi-arid to arid area has a very erratic rainfall and is prone to droughts of different duration. The frequency of drought-months with a rainfall of less than 75 per cent of the average rainfall for that month over the area as a whole, is between 20 and 25 per cent of the total number of months recorded

TABLE II. RAINFALL NORMALS, NORTH-WESTERN CAPE PROVINCE. (AFTER CLIMATE OF SOUTH AFRICA, WEATHER BUREAU.)

Name	Lati-tude	Longi-tude	Normal Rainfall in mm																
			Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year	Summer	percen-tage	Winter	percen-tage
Garies	30°34'	18°00'	2,3	3,8	5,8	11,2	15,5	23,6	16,3	20,1	12,5	8,6	7,1	3,3	130,1	30,9	24	99,2	76
Dubbelevlei	30°33'	21°31'	14,5	20,3	40,9	16,5	9,9	5,8	8,1	8,1	6,6	5,8	12,9	9,4	156,5	103,8	66	52,7	34
Carnavon	30°58'	22°08'	16,5	28,5	39,4	24,4	12,9	4,1	7,1	7,6	11,2	9,7	17,3	12,5	191,2	123,9	65	67,3	35
Leliefontein	30°19'	18°05'	4,8	10,7	12,2	21,6	41,4	65,8	46,5	57,4	45,7	18,5	18,0	7,4	350,0	71,6	20	278,4	80
Brandvlei	30°28'	20°29'	6,9	15,2	23,1	12,7	8,9	4,6	3,6	5,6	4,6	5,1	10,4	8,6	109,3	69,3	63	40,0	37
Van Wyksvlei	30°21'	21°49'	15,7	26,2	40,4	21,6	9,7	5,1	7,4	6,6	8,4	9,1	18,3	11,7	180,2	121,4	67	58,8	33
Prieska	29°40'	22°45'	26,4	34,5	45,0	28,5	12,7	2,5	3,8	4,6	7,1	13,2	18,8	16,6	213,9	154,7	72	59,2	28
Port Nolloth	29°14'	16°52'	1,5	2,3	4,8	4,8	6,1	8,6	9,1	7,9	4,3	3,6	3,6	2,8	59,4	18,6	31	40,8	69
Pella	29°02'	19°09'	4,1	11,9	14,5	9,4	6,9	2,3	2,8	1,0	3,0	4,6	8,6	3,8	72,9	47,5	65	25,4	35
Kenhardt	29°21'	21°09'	17,8	25,4	33,0	18,5	10,2	4,1	5,6	4,3	5,8	7,1	11,7	10,4	153,9	105,4	68	48,5	32
Marydale	29°24'	20°06'	21,1	23,4	42,7	24,6	10,2	3,1	5,8	6,3	4,3	10,4	17,3	13,7	182,9	128,6	70	54,3	30
Koegas	29°18'	22°22'	18,5	38,9	47,0	29,7	12,9	4,3	5,8	7,1	4,8	14,5	19,1	16,5	219,1	154,5	71	64,6	29
Niekerkshoop	29°19'	22°50'	22,6	44,7	55,4	32,8	15,7	3,6	6,6	7,1	3,8	14,7	23,1	19,3	249,4	179,8	72	69,6	28
Kakamas	28°46'	20°36'	16,0	19,8	27,4	16,5	9,9	2,5	5,1	4,1	3,3	6,1	11,7	8,1	130,5	89,1	68	41,4	32
Geelkop	28°38'	21°04'	17,5	24,6	36,8	16,0	11,7	2,8	3,6	3,8	2,8	5,8	11,2	11,4	148,0	107,3	72	40,7	28
Trooilapspan	28°38'	21°31'	23,9	27,7	47,7	29,0	14,5	1,8	3,8	4,8	5,3	11,7	18,0	16,5	204,7	145,5	71	59,2	29
Zwartmodder	28°01'	20°33'	20,3	30,2	33,5	18,8	10,4	1,5	2,8	2,3	3,3	9,7	11,7	13,7	158,2	119,1	75	39,1	25
Upington	28°27'	21°15'	20,6	35,6	42,7	27,4	13,7	1,5	4,1	4,6	3,6	10,7	16,8	17,8	199,1	144,2	72	54,9	28
Dunmurray	28°18'	22°42'	47,2	57,2	72,1	36,6	15,7	5,6	4,8	5,6	8,1	19,6	24,6	31,0	328,1	251,7	77	76,4	23

during more than 70 years. The frequency of severe droughts (below 60 per cent of the normal rainfall) is between 7 and 12 per cent (Climate of South Africa, 1960). The highest rainfall as a percentage of the normal, was 312 per cent, and the lowest rainfall as a percentage of the normal, 5 per cent. This extreme variability is typical of arid regions, and is the highest recorded of all regions in the Republic of South Africa (Climate of South Africa, 1960).

2.4.2 TEMPERATURE

2.4.2.1 TRANSVAAL

Because this is an inland plateau region lying at an altitude of 850 to 1 100 m above m.s.l., large temperature variations between the seasons are typical. The mean daily temperature is of the order of 22°C. Frost regularly occurs during winter, usually in June to August, but also in May and September. In summer the maximum temperature may exceed 38°C and the minimum 25°C.

2.4.2.2 CAPE PROVINCE

Due to the lower humidity, even greater temperature differences are found in these inland areas than in the Transvaal. As an example the average daily maximum and minimum per month at Prieska is given for the years 1957 and 1958 in Fig. 8. Frost occurs between May and September and maximum temperatures of over 38°C between October and March. Along the Orange River Valley below the Aughrabies Falls and at Kenhardt in the Hartebeest River Valley

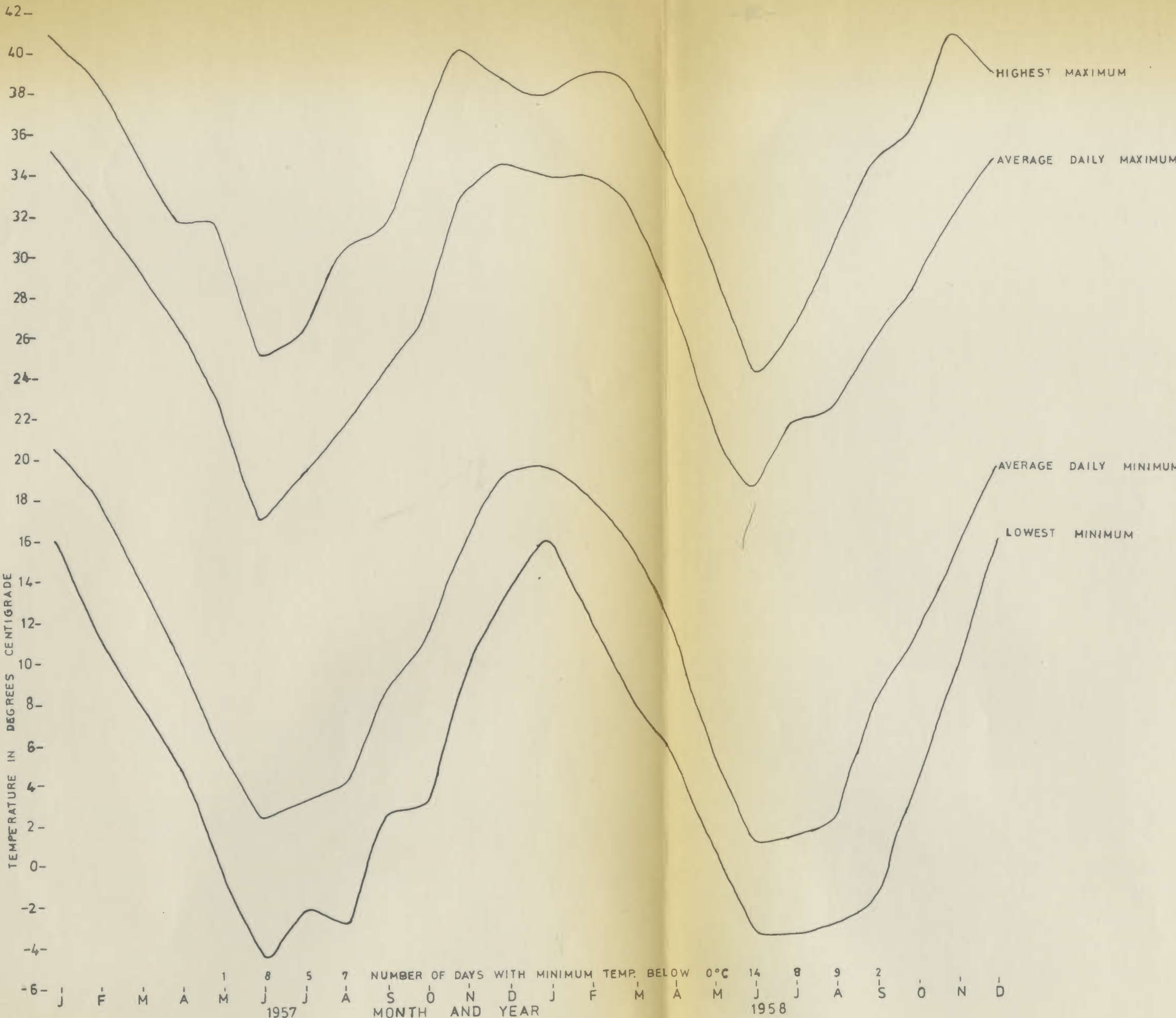


FIG. 8 - MONTHLY TEMPERATURES AT PRIESKA, N.W. CAPE PROVINCE.

some of the highest temperatures in the Republic of South Africa have been recorded. The mean annual temperatures are however lower than in the Transvaal, being e.g. 20,5°C at Upington and 18,5°C at Pofadder which are of comparable elevation to the Transvaal area. Below the Aughrabies Falls at Onseepkans, Goodhouse and Vioolsdrift it is, however, higher than in the Transvaal.

2.4.3 EVAPO-TRANSPIRATION

2.4.3.1 TRANSVAAL

Due to the fact that rain falls during summer when high temperatures prevail and transpiration in this densely-covered area is at its peak, a very high percentage of the rainfall is lost by evaporation and transpiration within a few days after precipitation. Theron (1947) has shown in Pretoria that very little water reaches a depth of 1 m below the surface during the summer growing season, even with high precipitation. It is only at the end of the growing season (March to May) that an appreciable percentage of the rainfall percolates down below the reach of grass roots.

The mean annual evaporation from open water surfaces is of the order of 1 900 to 2 100 mm (Rainfall Map,1945,Dept.of Irrigation).

According to Van Niekerk and Wand (1961) the evaporation from a soil surface during the first three days after rain or irrigation during the months of October to March, is 88 per cent of the evaporation from a free water surface during the same period. During these six months approximately 62 per cent of the mean annual evaporation takes place. The mean annual humidity of over 60 per cent, lack of strong wind, and smaller mean temperature differences are the reasons for the lower evaporation from this area compared to the Cape Province.

2.4.3.2 CAPE PROVINCE

Mean annual evaporation from free water surfaces varies between 2 000 and 2 800 mm, of which approximately 68 per cent occurs during the months of October to March. Mean annual humidity is relatively low, being of the order of 35 to 40 per cent. Together with the high incidence of wind and the bigger temperature differences, this causes higher evaporation losses than in the Transvaal. The low rainfall and smaller intensity of rainfall also mean that a much lower percentage of the rainfall reaches the ground-water reservoir, unless it is impounded.

2.4.4 WIND

In Transvaal the area under discussion has singularly little wind throughout the year. The wind velocities are only high immediately preceding thunderstorms, but this is of short duration, and for the rest of the year low wind velocities prevail.

The opposite is true of the Northern Cape area. During the greater part of the year wind from the north-west to west blows with varying intensity. It is usually a hot, dry wind accompanied by dust and sand. From the south and south-east cold winds blow with lesser intensity. These may sometimes cause precipitation in winter. The summer rain is caused by north-east to north winds and thunderstorms. As an example of wind intensity and frequency the average for the years 1959 and 1960 at Prieska is shown in Fig. 9.

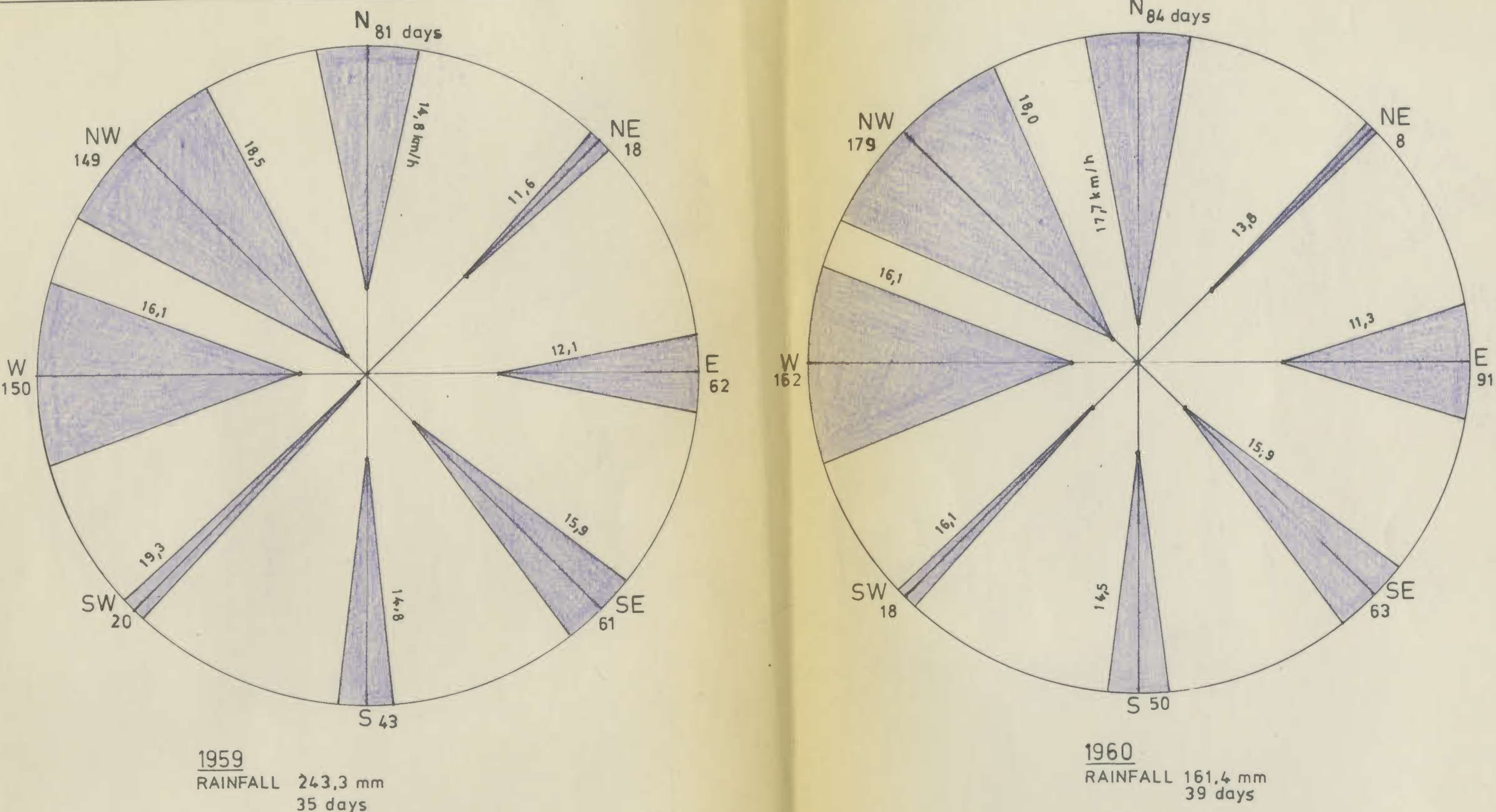


FIG.9 - FREQUENCY AND INTENSITY OF WIND AT PRIESKA, CAPE PROVINCE.

61 FREQUENCY IN DAYS PER YEAR
12,0 AVERAGE INTENSITY IN KM PER HOUR

3. GEOLOGY

3.1 STRATIGRAPHIC COLUMN

3.1.1 TRANSVAAL

The geological succession in the area north of the Witfontein Ridge is as follows:

Tertiary to Recent		Alluvium Surface Limestone Calcrete
Post-Waterberg Intrusives	Pilanesberg Complex	Syenitic and basic dykes, sheets and flows
Waterberg System		Sandstone and grit
Transvaal System	Dolomite Series	Dolomite, chert, lime-stone, shale
	Black Reef Series	Quartzite, shale
Post-Dominion Reef Intrusives	Gaberone Pluton	Red granite
	Basic Intrusives	Gabbro, pyroxenite
Dominion Reef System		Quartzite, conglomerate, grit, chert, acid lava, basic amygdaloidal and porphyritic lava
Post-Swaziland Intrusives	Archaean Complex	Granite, gneiss, grano-diorite, pegmatite
Swaziland System		Phyllite, slate, quart-zite, schist, amphibo-lite, lava

In this report only the formations older than and including the Dominion Reef System, and the geographically enclosed formations in the Archaean Complex are discussed. Outcrops are few and isolated, so that most of the information of the geological formations in the area is gleaned from boreholes. All the holes were drilled by percussion drills and therefore the samples were usually finely ground and the determinations of rock types were often tentative.

3.1.2 CAPE PROVINCE

The geological succession is approximately as follows, although it differs from place to place in this large area:

Tertiary to Recent		Alluvium, Wind-blown sand Surface limestone, calcrete, River terrace gravels
Post-Karoo Intrusives		Pipes and dykes of kimberlite, Dykes and sheets of dolerite, picrite, etc.
Karoo System	Ecca Series	Mudstone, shale, sandstone
	Dwyka Series	Tillite, shale, mudstone, quartzite, chert
Post-Koras Intrusives		Pegmatites, aplite, Namaqualand Granite-gneiss, adamellite, Grey Gneiss, granodiorite
Koras Formation		Quartzite, conglomerate, phyllite, schist, quartz-porphyry, basic lava
Post-Waterberg Intrusives		Dykes and sheets of quartz-porphyry, diabase, gabbro, norite, etc.
Waterberg System	Matsap Formation	Quartzite, conglomerate, shale

Post-Transvaal Intrusives		Dykes and sheets of diabase
Transvaal System	Dolomite Series	Dolomite, limestone, chert, shale
	Black Reef Series	Quartzite, conglomerate, shale
Post-Soetlief Intrusives		Granite, pegmatite
Soetlief Formation		Conglomerate, dolomite, ferruginous quartzite, limestone, basic lava, acid lava, quartz-porphyry
Post-Kheis Intrusives		Gabbro, norite, etc.
Kheis System	Wilgenhoutdrift Series	Basic lava, tuff, slate limestone, grit, ferruginous quartzite
	Kaaien Series	Quartzite, grit, conglomerate, granitised sediments
	Marydale Series	Basic lava, acid lava, quartz-porphyry, schist, quartzite, arkose, grit, amphibolite, granitised sediments

The sediments have been much folded and granitised. The so-called Namaqualand Granite-gneiss Complex which covers the major portion of the area, is today regarded as granitised sediments derived from the Kheis System, probably with the addition of magmatic material emplaced during the period of the Richtersveld magmatic activity (Von Backström and De Villiers, 1972).

3.2 DESCRIPTIVE GEOLOGY

3.2.1 TRANSVAAL

3.2.1.1 THE SWAZILAND SYSTEM

Because outcrops are extremely scarce in this area, it is hard to get an idea of the extent of the area underlain by rocks of the Swaziland System. If the proportions of boreholes drilled in granite and in sedimentary or metamorphic rocks are taken as criterion, about 40 per cent of the area between the outcrops of the Dominion Reef System and the Waterberg System, is underlain by rocks of the Swaziland System, and 60 per cent by granite. Part of the granite may however, be granitised sediments of the Swaziland System. For the discussion in this paper all the granite is treated as a single hydrological unit.

As mentioned above, outcrops of Swaziland rocks were seldom found. On a small kopje on Franksvley 807 and a slightly larger kopje on the adjoining Honingsvlei 63, quartzite and quartzitic schist were seen. The quartzite is often ferruginous, the kopje on Franksvley 807 containing magnetite and specularite. On Honingsvlei 63 the quartz-sericite schist grades into a gneissic rock. The strike of the beds is north-south and the dip 70^{o} to the east. On Crauseburg 198 similar quartzite was seen in gulleys. On Suid Brabant 248 pyroxenite was identified from a small hill, but this might be a later intrusion, probably post-Dominion Reef.

Amphibolite was found in a shallow excavation on Groenvlei 64. Quartz-mica schist occurs in gulleys on Paris 208 near the Crocodile River, and further north.

The basic amygdaloidal lava on Laastepoort 840 which is mapped as the basal portion of the Dominion Reef System, is intruded by granite and might form a portion of the Swaziland System, as suggested by Truter (1949). The intrusive granite can be correlated with the Gaberone Pluton, which is post-Dominion Reef. Due to the freshness of the lava and its low degree of metamorphism, it is, therefore, correlated with the Dominion Reef System. On several other farms further east, rocks regarded by Truter (1949) as probably the equivalent of the Onverwacht Series of the Swaziland System, are now correlated with the Dominion Reef System.

The chips out of boreholes, drilled out by percussion drills, form the chief source of information about the occurrence of the Swaziland System. According to the borehole records this system consists in the North-western Transvaal of the following rock-types:

(i) Quartzite, often sericitised, chloritised and felspathised. It is usually dark-coloured due to a variable content of iron ore. Sometimes it approaches a quartz-mica schist or quartzitic gneiss.

(ii) More clayey or shaly sediments have been altered to quartz-sericite schist and quartz-chlorite-sericite schist.

(iii) Amphibolite and amphibole-felspar gneiss were found in boreholes. These, as well as a metamorphosed basic rock from Dwaalboom 464, might have been lavas.

(iv) On the farm Brakspruit 789 gabbro was found in a borehole between depths of 60 and 90 m, but this might have been a dyke intrusive into the Swaziland System.

(v) Crystalline limestone occurred in boreholes on the farms Blinkwater 628 and Groenvlei 64.

(vi) In the same area as the above magnetic quartzite, sandy shale and chert were found in boreholes.

Because of the irregular spacing of boreholes and the lack of outcrops, it is impossible to draw up a stratigraphic succession for the Swaziland System in this area. The description of the rock-types in boreholes by drillers is also too vague and misleading to correlate the formation in one borehole with that in another several km away. The preponderance of psammitic material invites a correlation with the Moodies Series of the Swaziland System, but the crystalline limestone and the lava might be regarded as an equivalent of the Onverwacht Series, and some of the schist could be correlated with the Fig Tree Series. In that case the whole succession of the Swaziland System could be present.

3.2.1.2 ARCHAEAN GRANITE

Outcrops are nearly as scarce as for the Swaziland System. Weathered granite was however seen in several places in, or near to, the larger rivers and laagtes. On Mountjoy 1034 the granite forms a low kopje. On the southern portion of Krugerspan 804 a light-coloured coarse-grained granite crops out in several places. The colour is usually due to the felspar and varies from light pink or light grey to reddish. The grey colour is, however, sometimes due to small single specks of biotite. The granite is usually massive, but where it is foliated it forms a good aquifer. When the percentage of mica increases, as in a borehole on Engeland 862, it changes to a fine-grained dark-coloured gneiss. In an excavation on Laastepoort 840 the granite is gneissic with dark-coloured fine-grained layers alternating with light-coloured coarse-grained layers.

Quartz veins are found in the granite on Doornlaagte 110, Klipdrift 842, Krugerspan 804 and other farms. This seems to be a later pegmatitic phase of the granite and not younger intrusions.

On Fairlawn 661 a shear-zone with quartz-breccia cuts east-west through the granite. On Karoobult 619 and Tarentaalpan 803 similar structures are more silicified and therefore not such good aquifers as the former.

3.2.1.3 DOMINION REEF SYSTEM

This formation borders the area in which the older rocks are found on the south-west, south, south-east, and east, forming slightly higher ground and ridges running approximately parallel to the contact. In Botswana Cullen (1960) mapped acid lavas west of the Notwani River, due west of the area under consideration, which are correlated with the Dominion Reef System.

This system consists of basic, sometimes amygdaloidal lava of andesitic composition, followed by acid lavas of felsitic composition, and quartz-porphyries. Subordinate psammitic sediments are found in the lavas, consisting of quartzite, sandstone, grit, chert and conglomerate. The best outcrops are found in the ridges to the south of the granite on Laastepoort 840, Kameelhoek 45 and farms further to the south-east and east.

3.2.1.4 GABERONE PLUTON AND BASIC INTRUSIVES

The granite of the so-called Gaberone pluton seems to be intruded into the Dominion Reef System. The associated gabbro is shown as pre-Dominion Reef (AN2) and the granite as post-Dominion Reef (AG3) on the Geological Map of the Republic of South Africa (1970). From the outcrops seen in the northern portions of the Marico and Rustenburg Districts, and the results of a regional magnetic survey across the occurrence, it seems likely that the basic and acid rocks belong to a single complex which is post-Dominion Reef. Small outcrops and suboutcrops which may belong to this complex are found on Suid Brabant 248 (pyroxenite) and Noord Brabant 140 (granite).

Diabase dykes on the farms Klipdrift 842, Brakspruit 789, Engeland 862 and others, usually striking north to north-east, probably belong to this complex. The magnetic anomalies across the dykes are usually large positive anomalies, as illustrated in Fig. 11.

Outcrops of post-Dominion Reef rocks were seen on Kameelboom 857 and Krokodildrift 230. The granite is a massive reddish granite, usually coarse-grained, and the gabbro and associated basic rocks are also massive and very dark in colour. The rocks are usually fresh and weathering is much shallower than in the older granite.

3.2.1.5 TRANSVAAL SYSTEM

Small outcrops to the south, and more continuous ridges to the south-east, of quartzitic and shaly sedimentary rocks belonging to the Black Reef Series of the Transvaal System, border the older formations. Further to the north dolomite of the Dolomite Serieswas found adjacent to these formations. Because the hydrology of the Transvaal System falls outside the scope of this paper, these rocks will not be discussed here.

3.2.1.6 WATERBERG SYSTEM

To the north and north-east of the area under discussion, the Archaean formations are overlain unconformably by psammitic rocks correlated with the Waterberg System, formerly called the Loskop System. Reddish sandstome crops out on Brakspruit 789. In boreholes on Kameelfontein 556 light-coloured sandstone, quartzite, and a sandy shale were found.

The contact between the Waterberg System and the older rocks is nowhere exposed. On Brakspruit 789 a diabase dyke striking north-south, probably along a fault-zone, was seen between boreholes drilled in rocks belonging to the Swaziland System and the outcrops of the Waterberg System.

3.2.1.7 PILANESBERG DYKE SWARM

Numerous dykes of post-Archaean age strike north-east to NNW, i.e. in the same direction as dykes further to the south in the Witfontein Ridge, which belong to the Pilanesberg dyke swarms. Most of these dykes are syenitic in composition and, depending on the width of the dyke, they are fine-grained, coarse-grained or porphyritic with felspar phenocrysts. Basic dykes of doleritic composition strike in the same direction. Due to the fact that the magnetic anomalies on both of the above types are of the same order and of negative sign, the dykes are all regarded as belonging to the same swarms and to be of post-Waterberg age. These dykes can be traced for long distances by the magnetometer although outcrops are scarce. One dyke crossing Dwaalboom 464, was traced for more than 50 km by studying outcrops, magnetic anomalies and chips from boreholes.

3.2.1.8 TERTIARY TO RECENT

3.2.1.8.1 FERRICRETE

Ferricrete occurs on several farms on the Archaean granite, mostly in the eastern part of the area. The surfaces of some of the larger pans on Krugerspan 804 and Rietkuil 226 consist of ferricrete of unknown thickness. On Tarentaalpan 803, Ysterpan 66, and other farms near the contact with the overlying Dominion Reef System, ferricrete forms large outcrops in the low-lying areas.

3.2.1.8.2 SURFACE LIMESTONE AND CALCRETE

These deposits are found over large areas, from a thin layer of 1-2 m to 40-50 m in thickness as seen in boreholes. In one particular borehole on Graaff-Reinet 461 limestone was struck down to a depth of 68 m. On the Swaziland System and the Archaean Granite limestone or calcrete of at least 3 m in thickness was found in 46 and 48 per cent of the boreholes respectively.

Surface limestone and calcrete are usually found near laagtes, where most of the boreholes are drilled, but it seems logical to assume that at least a third of the area is covered by surface limestone and calcrete, sometimes under a thin covering of sand, black turf or red soil. The limestone is usually soft and crumbly, and does not form terrain features. Veins of limestone ("kalkare") standing out slightly above the surroundings, are found along the strike of dykes, and along certain horizons in the Swaziland System on Blinkwater 628 and Vaalpenspan 800. They are, however, not prominent features.

The calcareous formation is usually found in the form of calcrete at or near the surface, but becomes a purer limestone at depth.

3.2.1.8.3 ALLUVIUM

Practically the whole area is covered by soil, except for the occasional outcrops of ferricrete or calcrete. Most of the area is covered by a reddish sandy loam. On the granite, especially where the weathering is shallow, the soil is more sandy and lighter in colour. This type of soil is especially in evidence to the north and north-east of the Crocodile River. In and near valleys or pans, especially on the Swaziland System, black turf is found. The turf seldom covers large areas, being confined to narrow belts along the laagtes, or in and around the pans. From boreholes it was found that in the Swaziland System the ratio of boreholes starting in red loam or sandy soil to boreholes starting in black turf was 1,4 to 1. In the granite the proportion was 6,7 to 1.

The thickness of the soil varies between 0,3-1 m and 15 m, with an average thickness of 3-4 m. However, where the soil is very clayey it may be up to 25 m thick. In a few exceptional cases on Donald 93, Van Wykskraal 203 and Noord Brabant 140, soil and clay were found to depths of 34, 45 and 48 m respectively. On Donald 93 and Van Wykskraal 203 the alluvium seems to have been deposited in old river-beds. Most of the deep soil and calcrete in this area must, however, have been formed in situ. This can be deduced from the lack of relief and of a well-defined drainage system.

3.2.2 CAPE PROVINCE

3.2.2.1 THE KHEIS SYSTEM

The Kheis System is tentatively correlated with the Swaziland System but no direct evidence can be introduced that the two systems are contemporaneous. These systems are, however, the oldest known rocks in their respective areas and are of comparable ages.

3.2.2.1.1 THE MARYDALE SERIES

This series consists entirely of metamorphosed rock, having originally been sediments and lava flows. These formations have been intricately folded and deformed during several periods of orogenesis. Due to this complex deformation no satisfactory stratigraphic sequence of the Marydale Series has been compiled to date, but in the type area an approximate sequence could, from top to bottom, be as follows:

(a) Amygdaloidal basic lava, generally metamorphosed to amphibolite.

(b) Acid lava, acid granulite, dark-coloured quartzite, granite (granitised sediments).

(c) Amphibolite (metamorphosed lava), dolomitic limestone, lime-silicate rocks, marl (altered to amphibolite), subordinate quartzite and phyllite.

(d) Ferruginous quartzite, mica-schist, phyllite, serpentine rock.

(e) Granite with remnant structures of conglomerate, grit and quartzite.

(f) Grit, greywacke, and arkose, mostly altered to gneiss.

The greater part of the succession forms broad valleys or plateaux underlain by the granitised sediments. These sediments weather more easily than the quartzite and amphibolite, due to differential weathering of its constituents. The amphibolite seldom forms prominent terrain features, and is usually found along the slopes of kopjes and ridges. The quartzite and more quartzitic granite form the most prominent outcrops, forming ridges, kopjes and rounded hills between the broad valleys.

The Marydale Series is found throughout the North-western Cape Province from Prieska to the Richtersveld (De Villiers and Söhnge, 1959). According to Joubert (1971) the bulk of the Namaqualand gneisses are derived from this series. The sediments interbedded with the gneiss, notably the meta-quartzite which is prominent at Springbok and further east to the Ageneys Mountains, therefore belong to the basal portion of the Kheis System, i.e. the Marydale Series, not the Kaaien Series. It is, however, still possible that the meta-quartzite at Springbok belong to the Marydale Series and the quartzite in the Ageneys Mountains to the Kaaien Series. Du Toit (1968) remarked on the similarity of the quartzite interbedded with amphibolite near the top of the Marydale Series to the quartzite of the Kaaien Series.

Basic amygdaloidal lava, partly altered to amphibolite, was seen on the farms Kombaersbrand, Steynsrust and other farms in the vicinity. Due to the effect of weathering these rocks are not as prominent as the more resistant quartzite of the Kaaien Series.

3.2.2.1.2 THE KAAIEN SERIES

The contact between the Marydale and Kaaien Series is usually covered by rubble, but where it was exposed it was either a faulted, or a discordant contact. In the Richtersveld, De Villiers and Söhnge (1959) also found that the contact seems to be unconformable. This might suggest a considerable time lapse between the two series, but more evidence is needed. The Kaaien Series consists of the following:

(a) Quartzite, quartz-schist, and quartz-mica schist.

(b) Various granites, gneisses and granulites which Von Backström described as reconstituted sediments (1964).

(c) Conglomerate.

Von Backström (1964) regarded all the granulites, para-amphibolite, para-gneiss, dolomitic limestone, lime-silicate rocks, "kingzigite", pink gneiss, and some granite in the Keimoes area as reconstituted sediments of the Kaaien Series. Due to the fragmentary nature of the mapping, the different degrees of metamorphism in different areas, and the intricate folding and deformation, it is a moot point whether all of these metamorphic rocks belong to the Kaaien Series. Extensive additional mapping in this area is required before the stratigraphy can be satisfactorily unravelled, and a more accurate demarcation can be drawn between the Marydale and Kaaien Series.

The present author prefers to follow the old classification of Rogers and Du Toit (1910), who limited the Kaaien Series to psammitic rocks. Metamorphic rocks derived from arenaceous sediments with a little argillaceous material, can be added to the above. Only thin argillaceous members are intercalated with the arenaceous rocks e.g. mica-schist and sillimanite schist, even in the Richtersveld according to De Villiers and Söhnge (1959). These are ipso facto correlated with the Kaaien Series. The para-amphibolite, dolomitic limestone, lime-silicate rocks, some of the mica-schist, para-schist, para-gneiss, granulite, and even some of the quartzite grouped by Von Backström (1964) with the Kaaien Series, would then be grouped with the Marydale Series. The argument of Poldervaart and Von Backström (1950) that the quartzo-felspathic rocks of Kakamas must be metamorphosed Kaaien sediments because they are derived from arkoses, does not hold good. By geochemical analysis Kröner (1971) deduced that the southern Namaqualand gneisses were derived from arkosic rocks. Joubert (1971) correlated these gneisses with the basal portion of the Kheis System, i.e. the Marydale Series.

The Kaaien quartzite is often felspathic, which is also demonstrated by the wide-spread sericitisation, but some thick horizons consist of almost pure silica. The quartzite is often massive and coarsely recrystallised. Specks of magnetite could almost invariably be seen. Well-bedded horizons occur, usually parting along more sericitic layers or along thin layers of mica-schist. Due to different magnetite contents darker layers may be inter-bedded with lighter layers. Cross-bedding was found, but this was often obscured by later foliation. In the Richtersveld De Villiers and Söhnge (1959) grouped all the sediments above the volcanics of the Marydale Series as Kaaien. In this area the sediments consisted exclusively of quartzite, quartz-sericite schist, chlorite schist, quartz-chlorite-sericite schist, quartz-sillimanite-sericite schist, grit, phyllite and conglomerate. Several of the horizons were ferruginous.

Outcrops of the quartzitic rocks of the Kaaien Series are widespread due to their greater resistance to weathering. They often form the tops of ridges or mountains, especially in the area between Prieska, Marydale and Upington.

Joubert (1971) considered the quartzitic horizons in Namaqualand as probable equivalents of the Marydale Series and not the Kaaien Series. This would mean that the Marydale Series has a much wider distribution than was formerly believed, and the Kaaien correspondingly less.

At the base of the Kaaien Series south of Marydale, a coarse conglomerate was found, with orientated pebbles of quartzite, chert, granite and ferruginous quartzite. The fact that the age of the granite pebbles was determined from zircons as 1 100 M.Y. (Personal communication by A.J. Burger) casts doubt on the grouping in one system of the Kaaien Series and the Marydale Series, which is more than 2 800 M.Y. old.

3.2.2.1.3 THE WILGENHOUT DRIFT SERIES

This formation was found only in a few small areas near Upington, Vioolsdrift and in the Richtersveld. It consists mainly of sheared andesitic lavas, usually amygdaloidal, tuffs, agglomerate and quartz-porphyry, with intercalated sediments. The quartz-porphyry may be of younger age and therefore intrusive. The sediments are usually reddish in colour and arenaceous, consisting of quartzite and grit with subordinate slate, phyllite and a thin band of dolomitic limestone. The Wilgenhout Drift Series is not prominent and is usually very much sheared and weathered. The lavas are, however, much fresher and younger than that of the Marydale Series.

3.2.2.2 BASIC INTRUSIONS

The older norite, gabbro, etc. described by Gevers et al (1937), Von Backström (1964), and others, were found in limited areas and were of little hydrological significance. They occurred in short disjointed outcrops as dykes and sheets, and were folded by the post-Kheis orogenies. The rocks are usually dark-coloured and fine-grained basic to ultra-basic types. The dykes were found over a large area but sills and sheets were only seen south of Keimoes (Von Backström, 1964) and in the southern portion of the Richtersveld (Middlemost, 1965). Plugs, stocks and irregular bodies were described by Von Backström and De Villiers (1972) in the Vioolsdrift area.

3.2.2.3 THE SOETLIEF FORMATION

Although the correlation of this formation with the Dominion Reef System has been questioned (Haughton, 1969) recent geochronological determinations seem to strengthen the arguments for such a correlation. There is still some controversy over this formation in the Prieska-Marydale-Buchuberg Dam triangle.

On the Prieska-Marydale road the Soetlief Formation underlies the Black Reef Series of the Transvaal System unconformably. The basal Black Reef quartzite lies on sediments, basic lava and quartz-porphyry from north to south. The basic lava is the most wide-spread of the rock-types and covers a large area of more than 400 km^2 in the triangle mentioned above. Leube distinguished a three-fold division of the Soetlief Formation based on mapping in the above triangle (personal communication):

Top Zone - Dolomite, arenaceous limestone, tuff, lava, banded ironstone, quartzite.

Middle Zone - Basic lava, mostly massive andesite, quartz-porphyry, thin conglomerate bands.

Lower Zone - Lava, quartzite, conglomerate.

There was some doubt about the validity of this correlation, and subsequently Leube (1959) correlated most of the dolomite and limestone with the Transvaal System. He condensed the middle and top zones to an Upper Zoetlief Series with very subordinate limestone. The Lower Zoetlief Series conformed to his previous lower zone and was confined to an area near the Buchuberg Dam. The quartzites were renamed sub-greywackes, because a little felspar and a large amount of rock fragments were found in the rocks.

South of Prieska Du Toit (1907) drafted the following succession for the Soetlief Formation:

Amygdaloidal felsite

Rhyolitic lava or quartz-andesite

Green quartzite, grit, arkose

andesitic lava, breccia, tuff

Conglomerate.

The succession of the so-called Kuip Series (Du Toit, 1907)was as follows:

Arkose

Andesite

Arkose

Shale and slate

Dolomitic limestone

Flagstone

Arkose

Massive and amygdaloidal andesite

andesitic tuff

Rhyolitic lava

The Kuip Series is now considered to be the equivalent of the Soetlief Formation. The two formations are lithologically similar and their stratigraphic positions correspond.

3.2.2.4 GEELBEKSDAM GRANITE

This granite was named after the farm on which it was first recognised, and is shown as AG2 on the new Geological Map of the Republic of South Africa (1970). It is a leucocratic granite, usually coarse-grained to pegmatitic, and with a high silica content. Quartz veins are abundant. It is usually massive, but varying mica content sometimes gives it the banded appearance of gneiss. Both biotite and muscovite was found, and sometimes the granite was distinctly reddish. It is intrusive into the Kheis System and the Soetlief Formation, but not into younger rocks. On the farm Geelbeksdam it abuts against the Doornberg Fault to the east. The western limit is not very well defined due to surface coverings of sand and calcrete, but it is more or less indicated on the geological map (Fig. 6). Southwards it probably extends to the vicinity of Soetvlei, where it is covered by the Karoo System.

Some of the granite in this area is undoubtedly granitised Marydale sediments, and a greater geochronological age was determined by A.J.Burger (unpublished report) for samples of this rock than for the Geelbeksdam Granite. This includes the granite to the southeast of the Kuip hills, which underlies the Soetlief Formation in this area, and is therefore also granitised Marydale sediments.

3.2.2.5 THE TRANSVAAL SYSTEM

Overlying the Soetlief Formation unconformably a thick sedimentary succession was found, which was correlated with the Transvaal System. The normal sequence of Black Reef Series, Dolomite Series (formerly called the Campbell Rand Series and including a portion of the former Griquatown Series), and Pretoria Series (formerly called the Griquatown Series) was found. In the greater portion of the area the Doornberg Fault forms the western limit of the Transvaal System, where it abuts against all the older formations in the area. The hydrological properties of the Transvaal System fall outside the scope of this paper.

3.2.2.6 POST-TRANSVAAL INTRUSIVES

Diabasic and felsitic dykes and diabase sills were found intrusive into the Transvaal System. They are probably of pre-Matsap age (Leube, 1959) and the general strike is north-west, but this is not an invariable rule. They usually occur along shear zones, faults, or approximately parallel to the bedding planes in the Transvaal System. Only dykes were found west of the Doornberg Fault. Von Backström and De Villiers (1972) recorded diabasic and felsitic dykes from the Vioolsdrift area which are pre-Nama in age.

3.2.2.7 THE WATERBERG SYSTEM

The Ezelberg Range to the north of Marydale is formed by quartzite and conglomerate of the Matsap Series of the Waterberg System. To the north-east and north of the area under discussion the

Matsap forms the Langeberg range and other prominent features. The Matsap Series consists of conglomerate, quartzite and felspathic quartzite, called sub-greywackes by Leube (1959). It overlies rocks of the Lower Soetlief Formation up to the Pretoria Series of the Transvaal System with a large stratigraphic unconformity. Hydrologically it is of no importance due to the fact that as far as is known, no boreholes in this area have struck water in the Matsap.

3.2.2.8 POST-WATERBERG INTRUSIVES

The Annashoek Granite, first recognised on the farm Annashoek and described by Du Toit (1968) is a reddish, medium-grained rock, which is younger than the Kheis System and older than the Koras Formation. Du Toit (1968) found outcrops of the same type north of the Orange River on the farm Steenkampspan and further to the west. The associated pink aplitic rocks described by the author (unpublished report, 1963) are more porphyritic with phenocrysts of bluish quartz and felspar.

In the Transvaal System diabasic and syenitic dykes were found along thrust faults and normal faults formed as a result of the post-Waterberg orogeny. These dykes are definitely pre-Dwyka.

All the above rock-types are of doubtful age but are definitely post-Kheis and pre-Dwyka. They are most probably post-Waterberg and pre-Koras, but some of them may be post-Koras.

3.2.2.9 THE KORAS FORMATION

This formation was previously grouped with the Soetlief Formation, but recent geochronological determinations by Van Niekerk and Burger (1967) dated it as post-Waterberg. This age was already suspected, due to the finding of pebbles and boulders derived from the Pretoria Series and the Matsap Beds in conglomerate of the Koras Formation. It is now correlated with the Kapok and Doornpoort Series in South West Africa.

According to Du Toit (1966) the succession is as follows:

Reddish quartzite, grit and conglomerate
Quartz-porphyry, tuff and agglomerate
Andesitic lava sometimes amygdaloidal, tuff and agglomerate
Conglomerate, quartzite, grit shale
Quartz-porphyry
Shale, slate, grit, conglomerate, flagstone, arkose.

It is interesting to note that Rogers (1907) had realised that this formation could be younger than the Matsap.

3.2.2.10 GRANULITES

The following three rock-types are reconstituted sediments of the Kaaien Series, as described by Von Backström (1964). The metamorphism was probably post-Koras and the hydrological properties are the result of this metamorphism.

Various types of granulite were found in this area, and they were formed from altered lava or altered sediments of the Kheis System. Some of the acid granulites are probably altered acid or intermediate lavas, while others are altered argillaceous sediments. Outcrops seldom cover large areas except for the Aasvogelkop granulite described by Von Backström (1964), which forms the Piet Rooi's Mountains south of Keimoes. Mafic granulites were described by Poldervaart and Von Backström (1949), and by Joubert (1971) in widely separated areas. They were probably derived from volcanics.

3.2.2.11 PARAGNEISS

This term is used in a wider sense than by Von Backström (1964), for gneissic and granitic rocks of different composition and appearance, but all of them granitised sediments. The paragneisses in the area under discussion, are altered sediments of the Kheis System and they can therefore be correlated with the Namaqualand gneisses and the Grey Gneiss. Paragneiss sometimes graded into Grey Gneiss without a recognisable contact. The paragneiss is however better foliated, retaining more of the original structure of the sediments. The mafic gneisses (hornblende gneiss and biotite gneiss, etc.) may be partly derived from volcanics.

3.2.2.12 PINK GNEISS

This rock-type described by Poldervaart and Von Backström (1949), is found over relatively large areas, and is an important aquifer. It is probably a metamorphosed arkose, greywacke or felspathic sandstone. Von Backström (1964) remarked on the uniform gneissic quality, but in the field it was found that the percentage of quartz sometimes increased until the rock resembled a slightly felspathic quartzite in hand specimens. In this paper the term pink gneiss is used as a group name for a variety of gneissic and granitic rocks possessing the property of easy cleavage along parallel planes which might be related to the original bedding planes. The pink gneiss is usually rich in quartz, with sericite along the cleavage planes. Hydrologically it has several of the characteristics of a well-bedded quartzite.

3.2.2.13 GREY GNEISS

The Grey Gneiss of Von Backström (1964), the Namaqualand Granite of Gevers et al (1937), the Namaqualand gneisses of Joubert (1971), and the grey gneissic granite of Von Backström and De Villiers (1972) have approximately the same isotopic age of 1 050 M.Y. which is the period of the last major orogeny in this area. Other authors since Rogers (1915) have used various other names for the mobilised rock which bears an intrusive relationship to the Kheis System. It sometimes crops out as a coarse-grained granitic rock with numerous xenoliths of Kheis rocks, or as a highly-banded gneiss in which the xenoliths have been orientated parallel to the flow-lines. It can be of tonalitic, granitic or granodioritic composition, and is usually a hard and massive rock, weathering in rounded boulders or huge domes. It may also occur as lit-par-lit intrusions in the Kheis rocks. The term

"Grey Gneiss" is used as a convenient sack name for the group of granites and gneisses with the same isotopic age. The Grey Gneiss very seldom showed foliation or cleavage. It is regarded as the mobilised portion of the granitised sediments of the Kheis System, with the probable addition of magmatic material.

3.2.2.14 ADAMELLITE

This rock-type was exhaustively described by Von Backström (1964) as charnockitic adamellite-porphyry, and is usually remarkably dark-coloured when the small percentage of mafic constituents is considered, and is easily recognised in the field. It has probably a much wider distribution than described by Von Backström (1964) and Hugo (1969), both as emplacement bodies, and as dykes in the eastern portion of the area under consideration. Although the adamellite does not build prominent topographical features, outcrops are numerous due to its resistance to weathering. The adamellite often contains xenoliths of older rocks, and is characterised by blebs or grains of bluish opaline quartz. In numerous specimens examined from widely-separated places, copper or iron sulphides were always present.

A biotite granodiorite described by Visser (unpublished map) may be of the same age as the adamellite. Both of these rock-types are younger than the grey gneiss.

3.2.2.15 NAMAQUALAND GRANITE-GNEISS

Gevers (1937), and Von Backström and De Villiers (1972), considered

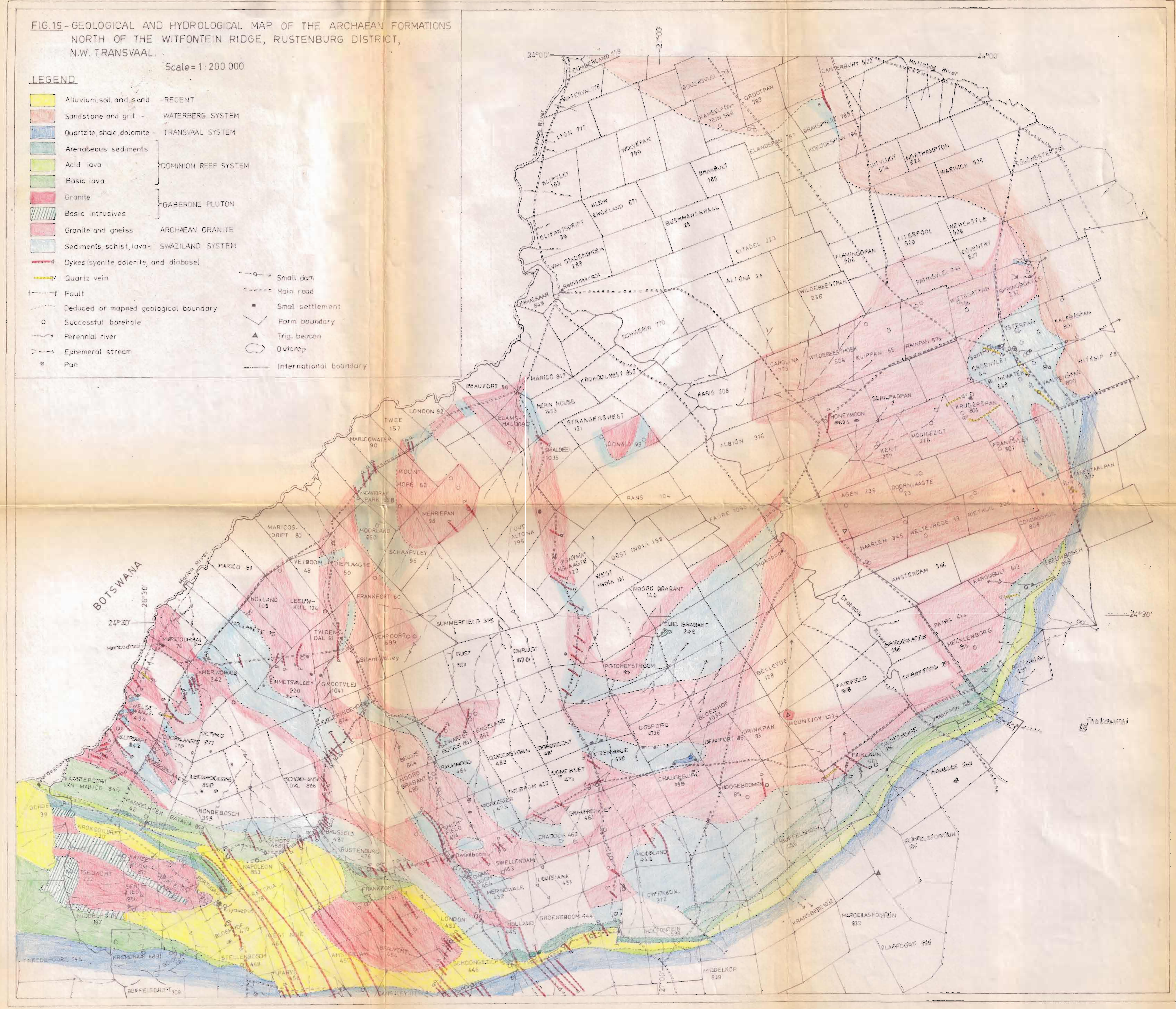


FIG.15 - GEOLOGICAL AND HYDROLOGICAL MAP OF THE ARCHAEAN FORMATIONS NORTH OF THE WITFONTEIN RIDGE, RUSTENBURG DISTRICT, N.W. TRANSVAAL.

this gneiss to be younger than the Grey Gneiss (or grey gneissic granite) because it has a cross-cutting relationship with the latter. Martin (1965) regarded the possible difference in age as small, being different phases of the same orogeny. The bulk of the Namaqualand granite-gneiss consists of granitic biotite gneiss, usually tending to form domes. It is often garnetiferous, and is regarded as a metamorphic product of the Kheis System with the addition of magmatic material (various authors). The intrusion of pegmatites in this area (described below) was probably the closing phase of the magmatic activity.

3.2.2.16 APLITE

Irregular bodies and dykes of aplite mapped by Von Backström (1964) and the author (unpublished report, 1963) are intrusive into the Grey Gneiss and adamellite. They are fairly uniform rocks of pinkish colour and the bodies were usually vertical. Phenocrysts of felspar and bluish quartz were sometimes prominent. Hydrologically this rock is not important in this area.

3.2.2.17 PEGMATITES

The pegmatites in this area seem to be of two ages viz. approximately 1 000 M.Y. and 940 M.Y. (Burger et al, 1965). Hugo (1969) classified them in two main groups, which were again subdivided. He recognised approximately 11 000 pegmatite bodies, ranging in length from a few cm to 2 km. Some of them were mineralised, but the bulk consisted mainly of quartz, microcline and muscovite or one or two of these minerals. They were either flat-lying or vertical, or at any attitude in-between, and were generally discordant to the country rock. Because of the fact that their felspars and mafic constituents usually disintegrate faster than the fine-grained country rock, and because of their cross-cutting habit, the pegmatites are hydrologically important in certain areas.

3.2.2.18 KAROO SYSTEM

3.2.2.18.1 DWYKA SERIES

The Dwyka Series covers the older rocks unconformably. It is almost unfolded and only very gentle dips were measured, seldom exceeding 1 or 2 degrees. The basal portion of the Dwyka Series is usually a coarse tillite, sometimes with shale and "boulder-shale", which was up to 250 m thick. The upper portion consists of alternating layers of shale, sandy shale, carbonaceous shale, sandstone and chert, and is correlated with the White Band. In several places a glaciated pavement and roches moutonnees were seen on the rocks over which the glaciers moved, e.g. south-west of Prieska, in the Ezelberge, between Marydale and Groblershoop, and near Loeriesfontein. In the area between Kenhardt and Springbok small remnants of the Dwyka, filling small pans or vloers, have the characteristics of varved clays.

3.2.2.18.2 ECCA SERIES

The Ecca Series in this area consists almost exclusively of mudstone. It is not described in detail because where it occurred, the thickness of Karoo sediments was generally too great for boreholes to penetrate to the underlying Archaean rocks before reaching the ground-water reservoir.

3.2.2.19 POST-KAROO DYKES AND SILLS

The post-Karoo dykes and sills are found over a wide area. They are generally of doleritic composition and in this area the strike is usually north-east to south-west or east to west, but this is not invariably the case. The dykes usually cut vertically or with steep angles across the older rocks, and were emplaced at a high temperature. The country rock was fractured and baked during their emplacement, and because of their relative youth, many of the fractures are still open. These intrusives are, therefore, hydrologically important.

3.2.2.20 KIMBERLITE INTRUSIONS

Kimberlite pipes are numerous in the gneiss in Namaqualand and Bushmanland, and at least two have been drilled for the purpose of supplying water for stock-watering. Dykes and pipes of undoubted kimberlite age were found in the Transvaal System to the north-east of Marydale, and in the Karoo System south and east of Prieska. The discovery of pyrope garnets with refractive indices around 1,72 in the area between Marydale and Kenhardt, may lead to the discovery of pipes or dykes under the covering of calcrete. Due to their fast rate of weathering, kimberlite intrusions are important as aquifers.

3.2.2.21 TERTIARY TO RECENT

The total area covered by outcrops of the different formations is small compared to the area covered by Tertiary to Recent deposits of calcrete, gravel, sand, alluvium and soil. This covering might be a metre or less of soil or calcrete, or up to 200 m of sand, gravel and clay in the drowned Koa Valley. The cover of calcrete is wide-spread and generally 1-10 m thick. According to Mabbutt (1955) the onset of calcification on the Bushmanland Plateau cannot have occurred later than the early Pliocene, which dates the onset of arid conditions.

Most of the soil and calcrete were formed in situ. Only the alluvium which is confined to the Orange River valley and some of its major tributaries, the river-terrace gravel along the Orange River, and the clay and gravel in the Koa Valley show signs of having been transported over long distances. Some pans are filled by calcrete or clay derived fom the nearby surroundings and washed in by local drainage systems. On Bundu, west of Prieska, fossil bones and teeth were identified in the calcrete in such a pan. Scree from ridges and mountains have seldom been transported over long distances.

The wind-blown sand, which covers large areas, is probably also of relatively local development. The sand has a typical reddish or orange colour except for isolated patches where it is considerably lighter in colour. The "white sand" is usually found in low-lying areas, or where the ground-water rest level is near to the surface.

River-terrace gravel was found as narrow strips near the Orange River and remnants are preserved at different elevations above the present river-channel. Near Rhenosterkop Island diamonds were retrieved from the gravel which lie at an elevation of 20 to 30 m above the river. The gravels are of no hydrological importance.

Because of the aridity of the climate physical weathering predominates. In the arenaceous sediments this is practically the only form of disintegration, whereas in the more argillaceous types and in the altered volcanics, chemical weathering plays a larger part. On the whole it was found that secondary structures due to physical weathering as exhibited by joints, cracks and other secondary openings, extended much deeper below the surface than the depth of chemical weathering.

3.3 STRUCTURE

3.3.1 TRANSVAAL

Due to the extreme scarcity of outcrops, very little is known about the structure of the formations in this area. The area in which the pre-Transvaal rocks are found, is elliptical in shape and seems to be a shallow anticlinal or dome-like structure, with the younger formations forming the rim of the dome. The rocks of the Swaziland System have been folded and probably faulted. The only measurable folding had a north-south strike and a dip of

70°. In the granite no structures were found, but quartz veins and east-west striking brecciated shear zones showed that it had been subjected to some deformation. The gneiss on Mountjoy 1034 showed planes of schistosity striking north-west to south-east and dipping to the south-west.

Dykes have been intruded at later stages in several directions, probably during post-Dominion Reef and post-Transvaal times. Basic intrusions and a younger granite, probably of the Gaberone Pluton, were intruded near the centre of the dome. The Dominion Reef sediments and volcanics dip away from the centre of the dome at the southern and eastern rims. At the eastern rim the dip is as high as 40°, at the south-east about 25°, and at the western rim of the outcrop 12° to 15°. Several cross-cutting faults were found in this formation, mostly on the south-eastern rim of the dome. To the north the Waterberg System overlies the older formations discordantly, with low dips away from the centre.

3.3.2 CAPE PROVINCE

In this area outcrops are much more abundant and the structures in the different formations are better revealed. A striking feature in this area is the persistance in the directions of the fold-axes from the Atlantic Ocean to the Transvaal System in the Prieska District, both south and north of the Orange River (personal communication by P.J.Joubert, and mapping by the author).

3.3.2.1 FOLDING

Four major directions of folding have been mapped in the eastern portion of the area:

(i) North-west to south-east. These seem to be the oldest fold-axes, and this is also the direction of strike of the large synclinorium in which the Kheis System is folded in the type area between Marydale and Upington. This fold-direction was also described in the Kheis System in the Richtersveld by De Villiers and Söhnge (1959). Later folding in a NNW direction which is post-Waterberg in age, was observed in the area west of Prieska. A younger direction of folding with a WNW strike, crosses these folds.

(ii) North to south. These fold-axes produced broad and gentle synclines and anticlines with an amplitude of 10 to 16 km. In the Okiep area the same type of open folds were reported by Benedict et al (1964), but it was considered by them to be post-Nama in age, probably due to renewed movement along the same axes.

(iii) North-east to south-west. This direction of folding is not very prominent and could be seen only where younger folding does not mask it. Von Backström (1964) also recorded this direction as one of less intense folding. According to Von Backström and De Villiers (1972) folding along these axial directions also pre-dated the north-south folding in the Vioolsdrift area.

(iv) East to west. Folds with this strike folded all of the older fold-axes. Joubert (1971) described this direction of folding during the 3rd episode of his first event of deformation of the Namaqualand gneisses, with overfolding to the south. He visualises repeated refolding along the same axes. Von Backström and De Villiers (1972) deduced that the earliest folding in the Vioolsdrift area was in this direction.

Folding along all of the above directions must have taken place after deposition of the Transvaal System, because they are developed in all the formations up to and including the Transvaal System.

(v) After the deposition of the Matsap beds new folding was developed as a result of pressure from the west. The fold-axes are approximately north to south and the amplitude of the folds 1,5 to 2,5 km in the Doornberg Range, with overfolding towards the east.

(vi) Gentle folding with axes striking east-west, which was mapped in the Asbestos Mountains, is probably post-Karoo. (Unpublished report by the author). An outlier of the Dwyka Series on the farm Le Rato, Kenhardt District, exhibited the same direction of folding.

3.3.2.2 FAULTING

The last period of major deformation, which probably coincided with the major orogeny of approximately 1 000 M.Y., caused large overthrusts and normal and reversed faults to develop. These are very much in evidence in the vicinity of the Doornberg Fault where graben and horsts with large throw have been mapped by the author.

Large faults to the west of the Doornberg Range in the vicinity of Marydale have a general strike of NNW to WNW, and are sometimes filled with quartz-breccia and calcite with a width of up to 100 m. Several of these fault-zones and shears have been mineralised, the large one on Vogelstruisbult west of Prieska being of major economic significance.

Between Marydale and Springbok the more important younger faults and shear-zones strike north to south or within 10^{o} of north, and are sometimes filled with quartz-breccia with a relatively large percentage of secondary openings. These structures are of major hydrological importance on the Bushmanland Plateau and the sand-covered area to the west.

In the area mapped by the author to the east of Upington large shear-zones were found striking north-east, NNE, north and north-west. These zones are intensely brecciated, up to widths of 500 m. They often form the only outcrops in a sand-covered area, because of the higher resistance to weathering of the silicified breccia. These shear-zones could be traced for long distances of up to 15 km. The quartz is of a low-temperature milky variety, and much epidote was formed. In one case on Vryheid, amethyst was found with the quartz. These structures are of major hydrological importance. Most of the boreholes in this area were sited on the breccia.

According to Von Backström and De Villiers (1972) normal faults were developed in the Vioolsdrift and Onseepkans areas after the Karoo sedimentation. These faults strike due north to NNW and are probably of the same age as the faults and shear-zones described above.

3.4 GEOCHRONOLOGY

Our present knowledge of the geochronological age of the formations, can be summarised as follows:

(i) The rocks of the Swaziland System are older than 3 300 M.Y. Although no dating has been done on the rocks from the North-western Transvaal they are correlated with the Swaziland System and must therefore be of equivalent age.

The greatest age recorded from the Cape Province is from a granitised breccia or agglomerate from the Marydale Series, collected by the author to the north-east of Marydale, of which ages of 2 920 and 2 926 M.Y. were determined by A.J.Burger (unpublished report). Granitised sediments of the Marydale Series south and south-east of Prieska, collected by the author, varied between 2 820 and 2 858 M.Y. One of these specimens was collected from the granite underlying the Soetlief Formation on Kuip and adjoining farms.

(ii) Post-Swaziland granites and basic intrusives are younger than 3 100 M.Y. The Archaean Granite of the North-western Transvaal must be of comparable age. The granite in Pietersburg District was determined by Burger et al (1967) as approximately 2 650 M.Y. old, which means that it is younger than the Dominion Reef. This is probably also the age of the Gaberone granite in the northern part of the Rustenburg District. The Geelbeksdam granite has been dated by various methods by Nicolaysen and Burger (1965) and A.J.Burger (unpublished report). Ages of between 2 477 and 2 710 M.Y. were determined, which correspond with the age of the Pietersburg granite. The basic intrusives in the Kheis System, south of Kakamas, may be of the same age.

(iii) The Dominion Reef System is 2 800 ±60 M.Y. old as determined by Van Niekerk and Burger (1969). The Soetlief Formation is older than the intrusive Geelbeksdam granite, and therefore of comparable age to the Dominion Reef System. It is probably younger than the Marydale granite of 2 820 to 2 858 M.Y.

(iv) The Transvaal System is probably 2 000 to 2 300 M.Y. old, being older than the Bushveld Igneous Complex which has an age of 1 950 M.Y. In the North-western Cape Province the Vioolsdrift granite is approximately 1 850 M.Y. old, according to De Villiers and Burger (1967).

(v) The Waterberg System, including the Matsap Beds, must be older than 1 400 M.Y. and younger than 1 900 M.Y.

(vi) The Pilanesberg Complex is 1 300 to 1 400 M.Y. old according to Burger et al (1967). A comparable age was determined on a sample of euxenite from Steinkopf viz 1 430 M.Y. (Burger et al, 1965).

(vii) The Koras Formation has an age of 1 085 ±80 M.Y. as determined by Van Niekerk and Burger (1967). This is correlated with the Kapok and Doornpoort Series in South West Africa, which have a comparable age. Adamellite from Jacomynspan had a slightly higher age of 1 170 M.Y. (unpublished report).

(viii) In the Cape Province an extensive belt with approximately 1 000 M.Y. old orogeny occurs, which extends into Natal (Nicolaysen and Burger, 1965). During this orogeny much of the granitisation in this area occurred. Granite from a deep borehole at Fraserburg had an age of 970 M.Y. (unpublished report) and several of the granites, pegmatites and quartz-sericite schist had ages between 920 and 1 100 M.Y. (idem, 1965 and unpublished reports). The pegmatites are of two ages according to Hugo (1965), the older being approximately 1 000 M.Y., and the younger between 890 and 940 M.Y.

(ix) The Dwyka tillite falls between the ages of 350 and 300 M.Y. in this area, and is probably slightly older than the same formation in the south-western Cape Province (personal communication by Dr. Edna Plumstead).

4. PREVIOUS INVESTIGATIONS OF GROUND-WATER RESOURCES

4.1 TRANSVAAL

No systematic geohydrological work had been done in this area before the present survey was commenced towards the end of 1952. Boreholes were drilled on the following information:

(i) Likely spots selected by the owners of farms or other laymen, usually at concentrations of trees, or in laagtes or pans.

(ii) Sites selected by drillers or boring inspectors based on their experience of the occurrence of ground-water during years of drilling, on farms in the same area or comparable areas.

(iii) Sites selected by water diviners making use of various techniques, and using a wide variety of aids to impress the farmers.

(iv) Sites selected by geologists employed by private companies or by the government. Use was made of geological and geophysical methods. Usually a single farm or a few farms were visited for a short period to select the sites. Records of these selections are sketchy, and usually do not give reasons for the selection of the site, nor the results of the drilling.

As far as could be ascertained geophysical work included magnetic surveys and electrical resistivity methods, using the

Wenner Method with a Gish Rooney type of instrument. The method of Constant Separation Traverses seems to have been used extensively.

The results of drilling on selections by geologists prior to 1952 which could be traced, are as follows:

Number of boreholes drilled on selections by private geologists	25
Percentage of boreholes yielding more than 0,45 m^3/h	24
Number of boreholes drilled on selections by government geologists	40
Percentage of boreholes yielding more than 0,45 m^3/h	37,5
Total number of boreholes	65
Percentage successful	32,5

Because of the fact that unsuccessful boreholes are usually filled up and levelled, and that new owners have no knowledge of unsuccessful holes drilled by the previous owner, it was impossible to locate all the boreholes drilled in this area before 1952. The following were traced:

Total number of boreholes drilled up to 1952	879
Percentage of boreholes yielding more than 0,45 m^3/h	35,4

Of these so-called successful boreholes several had dried up by 1952, or weakened to an uneconomic level, while others were never used because stronger supplies, which could be developed more economically, were drilled close by.

In 1935 Frommurze (1937) had collected the results of 234 boreholes in this area, with 50 per cent of them successfull. This figure was lower than anywhere else in the Union.

From the above can be seen that the geologists selected approximately the same percentage of successful boreholes as the laymen up to 1952. One reason for this result could be that geologists were much more costly to employ than water diviners or experienced drillers, and therefore they were not consulted before all other methods of finding water on a farm had failed. They were therefore confronted with the "hopeless" problems in an area where the geological evidence at the surface was extremely scanty.

4.2 CAPE PROVINCE

Because of the scarcity of water, the depth to the water rest level, the hardness of the rock to be drilled, and the uncertain quality of the ground-water, the Department of Water Affairs has for decades been helping farmers in this area to find water. Most of the boreholes were drilled by government drills under a generous subsidy scheme.

Several private geologists had been operating in this area, but no reports could be traced of the number of boreholes selected, nor of the results.

4.2.1 GEOLOGICAL AND GEOPHYSICAL REPORTS

The following reports on the selection of borehole sites and the hydrology in the area have been traced :-

(a) Enslin (1944) described the selection of borehole sites on a few farms in the Kenhardt District, and stressed the importance of the electrical resistivity method as an aid to the correct siting of boreholes. His work covered a small area to the east and south-east of Kenhardt.

(b) Taljaard (unpublished report) analysed the results of a large number of electrical resistivity depth probes and magnetic readings in the Kenhardt District.

(c) Frommurze (1937) mentioned that up to 1935 "boreholes are very sparsely distributed over this vast tract of country". He found that 68 per cent of the boreholes yielded insufficient water in the Kenhardt District and 52 per cent in Namaqualand and Bushmanland, but did not give the number of boreholes analysed. In the latter area 33 per cent of the boreholes were drilled deeper than 91 m.

(d) Vegter (1953) discussed the results of borehole selection by geophysical methods on certain farms in the Kenhardt and Prieska Districts between the Orange River and the outcrops of the Karoo System. Only the electrical resistivity method was used, employing a Gane-Enslin Apparatus and the Wenner configuration of electrodes. Depth probes were interpreted empirically for depth to solid rock. According to Vegter very good results were obtained by this method of interpretation, the average mistake being only 7,5 per cent. A total of 710 boreholes were analysed for depth of borehole, percentage of success, yield, depth at which water was struck, and rest level. Some of the more important conclusions are:

Percentage of boreholes yielding water shallower than 73 m	85
Percentage of boreholes with rest level shallower than 61 m	96,3
Percentage of the total number of boreholes which were successful	31

Of 100 boreholes investigated by geophysical means, 40 had weathering deeper than the ground-water rest level, and 57,5 per cent were successful. In 37 the weathering was shallower than the water table and only 8,1 per cent were successful. Thirty five boreholes were drilled on zones of brecciation, of which 40 per cent were successful. (Here it must be noted that it was not established how many of these boreholes penetrated the brecciated zone below the ground-water rest level.)

Vegter recognised five types of aquifers:

(i) Recent sand, calcrete, and alluvium in laagtes where a water table was shallow enough to occur in the unconsolidated material. Good aquifers.

(ii) Weathered granite and gneiss, if the weathering extended deeper than the rest level.

(iii) Foliation and bedding-planes in gneiss, granulite and sediments where these planes were open to a greater depth than the rest level.

(iv) Joints, cracks and fissures in semi-weathered gneiss and granite and in folded sediments.

(v) Zones of brecciation and mylonitisation along shear zones or faults, sometimes several kilometers long. It was usually impossible to trace these zones geophysically where they did not crop out.

Vegter correlated the resistivity with yield and percentage of successful boreholes, but the graphs were very irregular and no satisfactory conclusion could be drawn from them. The quality of the water was usually bad, due to an excess of dissolved solids, especially sulphates. The quality of water from the Karoo cover and the Archaean rocks were similar. He concluded that good supplies are found in the Kaaien quartzite and in amphibolite, whereas the grey gneiss and adamellite yield very little water. No water was found at the contact between the Karoo System and underlying rocks. Brecciated zones are good aquifers but they were hard to trace. There did not seem to be any recharge of ground-water in this area.

(e) Kok (1963) described the occurrence of ground-water in similar rocks across the Orange River in South West Africa. He concluded that most of the ground-water is found along brecciated zones and fissures, especially where they cross drainage lines.

The bulk of the water was struck at depths of 91 m or less (98,5 per cent), and the average rest level was at 61 m or less. Almost 64 per cent of the boreholes were successful.

(f) Wilke (1961) discussed an area in Fraserburg District with a Karoo System cover, and comparable rainfall and topography to the area discussed in this paper. He concluded that all, or nearly all, of the ground-water occurs along secondary structures viz. joints, fractures and cracks, usually formed as a result of the intrusion of dolerite sheets and dykes.

5. GENERAL ASPECTS OF GROUND-WATER INVESTIGATIONS

5.1 REQUIREMENTS

5.1.1 TRANSVAAL

This area was only sparsely populated up to 1940 except in the southernmost portion. This was partly due to the prevalence of malaria along the rivers and in the flat tree-covered area north of the Witfontein Ridge, and to a variety of deadly cattle diseases. Remedies for most of the above diseases were found, and during and after the Second World War prices of property rocketed. The result was that the area was much more intensively farmed. Farms were divided into smaller units, fenced, and subdivided into camps and the livestock population multiplied. Every camp had to be provided with a drinking supply for livestock, and the demand for boreholes increased by leaps and bounds.

Because of the low rainfall (average of 502 mm per annum) and the very high evaporation from free water surfaces (average of 2 030 mm per annum) there is no permanent stream in this area, except for the Marico and Crocodile Rivers which rise in higher rainfall areas to the south and flow for 6 to 8 months per year. The lack of prominent drainage channels and the general flatness of the area, give rise to the fact that there are hardly any suitable sites for even small dams in the whole of the area. Therefore the farmers have to depend on ground-water for all of their requirements. It is estimated that a total of 6 000 m^3/day is required for stock-watering and domestic use in the area under discussion. Except for short periods of days or weeks after a good fall of rain, all the water must be pumped from boreholes or wells. The problem is intensified by the fact that very little wind blows in this area. Therefore windmills cannot be used, and power pumps are too costly to operate economically on boreholes yielding less than 1 m^3/h.

At the start of this survey many farms had no permanent supplies, so that water for domestic use had also to be found. The quality of the water and the location of the borehole relative to the farmhouse were of prime importance in these cases.

5.1.2 CAPE PROVINCE

The average rainfall is much lower than in the Transvaal, ranging between 50 and 250 mm per annum, while the yearly evaporation from open water surfaces ranges between approximately 2 000 and 2 800 mm. (Rainfall Map, 1945, Weather Bureau). There is very seldom any flow of surface water except in the perennial Orange River which rises far outside the area in the Drakensberg Mountains. The rainfall is generally too low to cause infiltration to the ground-water reservoir without surface storage, except in isolated areas where conditions are exceptionally favourable. Due to the more rugged topography than in the Transvaal, large numbers of small earthen dams have been constructed by farmers, although they might only store water for a few months once in 2 to 3 years. Because of the generally low humidity (annual average of 35 to 40 per cent) a large field capacity must be saturated before ground-water can percolate down to a reservoir. The depth to the water rest level is usually large, so that it is only below pans and dams, the larger laagtes with low gradients, and over outcrops and sub-outcrops of permeable rocks, that water can percolate down to replenish the ground-water supply. Due to the low rainfall there is no general water table, but the ground-water occurs in isolated bodies, usually of very limited volume.

As in the Transvaal the farmers are totally dependant upon ground-water for all their requirements, except for a few days or weeks after the occasional rains, or as long as their stock can be watered at the pans and dams on their farms. Development of grazing control, sub-division of farms, and efficient camping have caused a large increase in the live-stock population and have multiplied the demand for boreholes, sometimes in areas that had previously been regarded as untenable. After the Second World War many farms which up to then had been Government Land, were allotted to returned soldiers on a permanent basis, and they had to be provided with bore-holes.

Sheep and goats which require much less water per head than cattle, are practically the only livestock on farms in this area. The sparse vegetation necessitating larger grazing area per head of livestock, and the prevalence of wind in this area, make windmills a universal sight, and small supplies of 0,3 m^3/h or even less, have been successfully used for years. The quality of water can be very poor before sheep and goats cannot use it, and in this respect it is easier to find water for livestock than in the Transvaal.

Domestic supplies have, however, to be of better quality and higher yield. Farm-houses are usually sited where the best ground-water supplies had been found, even though it is on an extreme corner of the farm. Several farm houses may be grouped together near a common boundary or beacon where shallow supplies had been obtained, near a river, or near an intermittent or dried-up spring.

One of the biggest problems in both areas is the finding of adequate supplies of ground-water near to farm-houses or at the common beacon of several camps where costly structures had been erected, and where the existing supply has dried up, has become too salty for use, or has decreased to an uneconomic level. These failures are usually due to overpumping of a restricted aquifer, and no new siting of a borehole will provide more water from the same aquifer.

5.2 PROCEDURES IN LOCATING GROUND-WATER

Several methods or combinations of methods were used for locating ground-water supplies; usually a combination of geology, photo-geology, geophysics and statistics.

5.2.1 GEOLOGY

5.2.1.1 TRANSVAAL

Because of the lack of surface relief, the monotony of the tree-covered landscape and the almost total absence of outcrops, no boreholes could be selected by means of surface geology or topography on the Swaziland System or Archaean Granite. No detailed geological maps of the area exist, and the structure in these formations cannot be deduced from the surface. Due to the thick covering of soil, sand and calcrete it is also impossible to detect the presence of geological structures or dykes on aerial photographs. As noted previously the type of soil could in some instances be deduced from the vegetation, and the probable underlying rock-type from this, but not the presence of aquifers or the most suitable site for the selection of a borehole. Due to the deep ground-water rest level, concentrations of ground-water were seldom reflected in plant growth.

It was only in the Dominion Reef System that outcrops and structure could be seen, but even in this formation most of the boring sites have to be selected geophysically. This is due to the fact that outcrops are mostly confined to the ridges which form the watersheds where ground-water does not accumulate.

5.2.1.2 CAPE PROVINCE

5.2.1.2.1 GEOLOGICAL MAPS

Relatively small portions of this area have been mapped in detail. Except for the pioneering work of Rogers and Du Toit (1906 to 1910) there were few published geological maps on a scale large enough to show linear structures, which could be utilised for the selection of borehole sites at the time of the present survey. At present there is much activity in this area, especially after the discovery of an important zinc-copper deposit west of Prieska. The geological mapping is, however, carried out primarily for economic minerals in small selected areas. Only the geological maps by De Villiers and Söhnge (1959), Von Backström (1964), Hugo (1969), Joubert (1971), Von Backström and De Villiers (1972), Visser (unpublished), Van Vuuren (unpublished), Leube (unpublished and largely outside the area), Drewes (unpublished) and the present author (partly published with Von Backström, 1964) have the necessary detail from which suitable areas for the selection of borehole sites can be deduced. Various other geologists of the Geological Survey and the Precambrian Research Unit of the University of Cape Town have dealt with specific problems in selected areas, usually of economic significance, with very little attention to the structures which may be of hydrological importance.

5.2.1.2.2 PHOTO-GEOLOGY

For the selection of borehole sites use was made of air photos to map specific areas, or to do photo-geological surveys. Although outcrops are numerous in certain areas, it happened all too often that contacts between different formations were covered by scree, rubble, calcrete, wind-blown sand, alluvium or soil. The following could be deduced from air photos:

(a) Secondary structures.

(i) Folding. Infiltration takes place along bedding-planes and in porous structures developed in the crests of anticlines. Synclines may form basins for the accumulation of groundwater. In the Marydale and Kaaien sediments and in some of the reconstituted sediments these structures are sometimes seen on air photos.

(ii) Joints and fissures, especially the more prominent systems of joints along which shrubs or trees can be traced.

(iii) Shear-zones, sometimes mylonitised and brecciated, and with the intrusion of secondary quartz, calcite and fluorite. Shear-zones can be traced on air photos by lines of vegetation, limestone veins ("kalkare"), a slight topographic trough or ridge, or outcrops of white quartz.

(iv) Faults or thrusts, either of local or regional size and of small or large throw. These can often be distinguished from shear-zones by the difference in vegetation or soil adjacent to the fault, and by the usually greater horizontal length.

(v) Dykes and quartz veins, many of which were intruded along existing shear-zones or faults. Often these structures do not crop out, but can be traced on air photos by vegetation, calcrete, or topographical differences due to differential weathering of the dyke or vein with regard to its surroundings.

(b) Topographical evidence which can be deduced from air photos may have an influence on the movement of gound-water.

(i) Drainage lines are usually related to the geology or structure in the area. This is also true for pans, dunes and abrupt changes in relief.

(ii) Differences in vegetation, especially when sharp and distinct, indicate the presence of geological boundaries or geological structures. An example was the thick growth of driedoring (<u>rhigozum trichotonum</u>) on the mica schist and the more sparse and variegated vegetation on the granulites in the area mapped by the author.

(iii) Dip and strike of beds can be deduced photo-geologically and used for hydrological interpretation.

5.2.1.2.3 GEOLOGICAL INTERPRETATION IN THE FIELD

Before selecting a borehole site, or before starting geophysical investigations the evidence garnered from geological maps or air photos, must be carefully checked in the field. Strike and dip can sometimes be measured and contacts traced on the surface. The geological evidence must be thoroughly evaluated before geophysical work can be of any value.

5.2.2 GEOPHYSICAL SURVEYS

5.2.2.1 TRANSVAAL

Several different techniques were used in this area.

5.2.2.1.1 MAGNETIC

The Watts Vertical Variometer was used throughout the area for all the surveys. The different instruments in use were correlated at base stations and sub-bases and the readings reduced to a common norm. No absolute values were determined but for long traverses an arbitrary base value was used to which all readings were reduced. Diurnal variations and temperature gradients were too small to influence interpretation and were ignored, except where very small anomalies were traced across certain structures or geological boundaries. Fixed points and base stations were pinpointed on air photos or surveyed by plane table and alidade, and transferred to base maps.

Along main roads in the area more than 9 000 magnetic stations were surveyed over a total distance of more than 260 km.

The results can be summarised as follows:

(i) The normal reading remained extraordinarily constant over the whole area in which readings were taken, including the Swaziland System, the Archaean granite, the Dominion Reef System, the Gaberone Complex and the Transvaal System up to the Dolomite Series. This means that there is no regional magnetic gradient and the differences from normal are due to magnetic anomalies. The differences between stations 30 m apart were usually within the degree of accuracy to which readings could be taken, which is approximately 0,5 division (15 gammas). As an example the total difference in the readings at 50 stations (1,6 km) along the road from Dwaalboom to Kayaseput was only one division (30 gammas).

(ii) Magnetic anomalies were of four types:

(a) Due to basic and acid dykes striking north-west or NNW, and associated with the Pilanesberg dyke swarm. All of these anomalies were negative, symmetrical, and of the order of 450 to 3 000 gammas. An example of the anomalies across such a dyke on Smithfield 474 is given in Fig. 10. The widths of the dykes as deduced from the anomalies according to the method of Maree (1943)were usually 30 to 60 m.

The number of dykes must be large. On the road from Bloemhof 479 via Dwaalboom 464 to Somerset 471, a distance of less than 40 km, 32 negative anomalies were found, all with amplitudes as described above. In several cases the anomalies were proved by means of boreholes to be due to dykes.

(b) A few symmetrical positive anomalies, striking

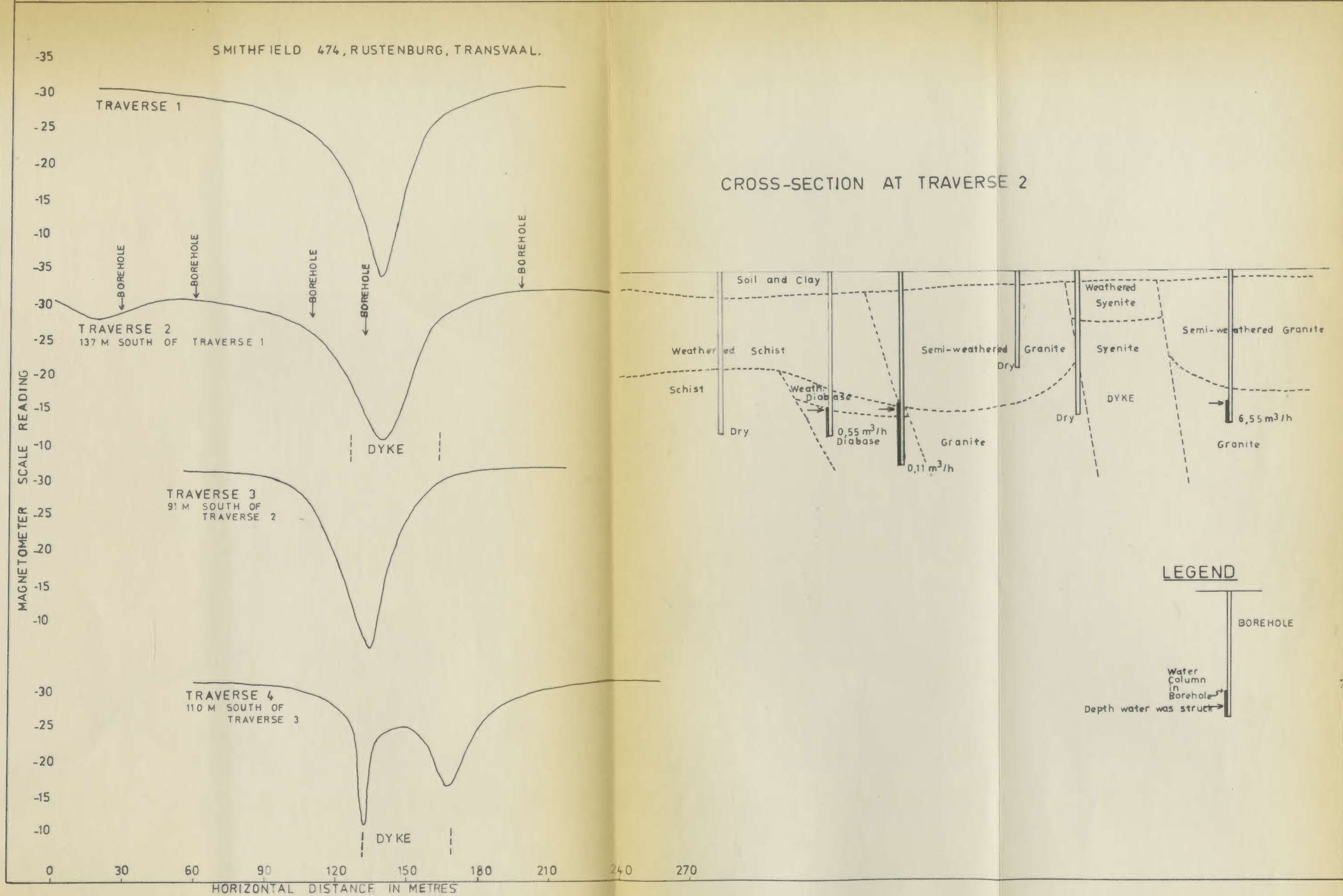


FIG. 10 - ANOMALIES ACROSS DYKE OF PILANESBERG AGE, N.W. TRANSVAAL

north-east to ENE are also attributed to dykes, probably of the Gaberone Comlex. The anomalies are comparable in size to those due to Pilanesberg dykes. Two positive anomalies were traced on Doornlaagte 110 and Zwartebosch 863, but no samples of the dyke-rock could be obtained. Examples of the anomalies are shown in Fig. 11.

(c) Due to varying amounts of iron oxides in quartzite and other rocks of the Swaziland System, magnetic reading on these rocks were irregular, sometimes varying between wide limits, whereas magnetic readings on the granite remained constant. Although the irregular readings might vary only by 60 to 150 gammas, or be fairly constant but varying appreciably from the normal as at Ysterpan 66, these irregularities were found wherever rocks of the Swaziland System were struck in boreholes. On Koedoeslaagte 49 and Laastepoort 840, the magnetic irregularities reached peak amplitudes of 3 700 gammas.

(d) On Kameelboom 857 and Port Elizabeth 855 two traverses showed a gradual change in the magnetic readings over distances of 1,6 and 4 km. The anomalies were nearly symmetrical and reached negative values of 1 350 and 2 250 gammas below normal. These anomalies seem to be associated with the Gaberone Complex.

(iii) For the specific purpose of selecting borehole sites, short magnetic traverses were done in selected areas. Several thousand magnetic stations were surveyed for this purpose.

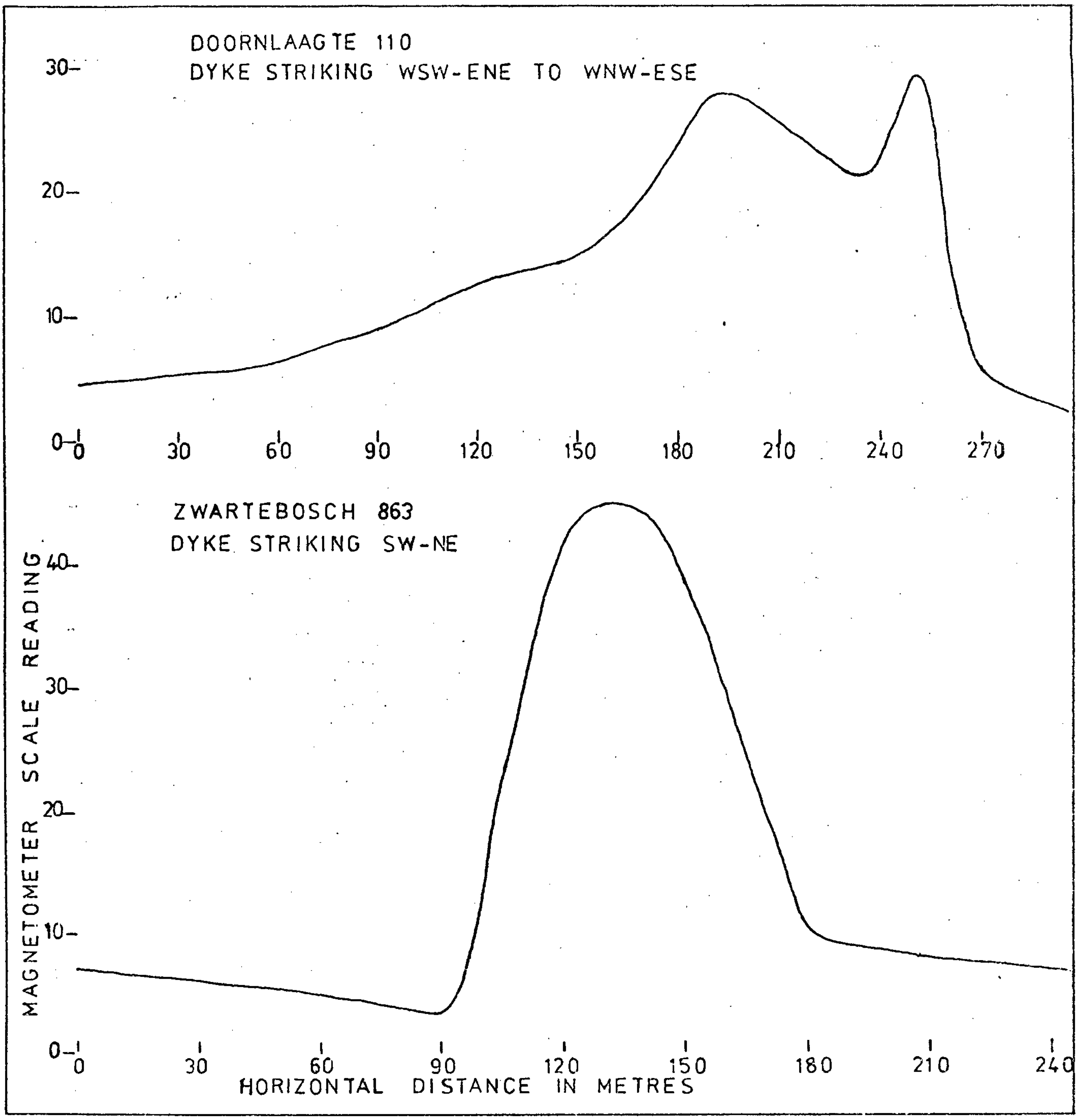


FIG.11 - ANOMALIES ACROSS DYKES OF POST-DOMINION REEF AGE, N.W. TRANSVAAL.

On the farms Koedoeslaagte 49, Klipdrift 842, Smithfield 474, London 453, Dwaalboom 464, Bloemhof 479, and Merinowalk 462 it was proved by boreholes that the magnetic anomalies were due to dykes, usually syenitic or doleritic in composition. The boreholes were not always successful but the percentage of successful boreholes near or next to dykes was appreciable higher than the average for the area.

5.2.2.1.2 ELECTRICAL RESISTIVITY

For this work a Gish-Rooney type of instrument, designed by Dr. J.F.Enslin (of the Geological Survey) and Dr Gane (of the Bernard Price Institute for Geophysical Research) was used (Enslin, 1944). The sensitivity and range were adapted to South African conditions, especially the semi-arid and arid regions where high contact resistances and high surface resistivity are found. Because the current is periodically reversed, hard steel electrodes could be used for making contact with the soil or calcrete. This instrument was further developed in the Geological Survey Workshop. Besides building the instrument more compactly, introducing an electric motor to operate the commutator, and improving the type and quality of components, one of the more important alterations was the addition of a selector switch by the author, to facilitate the equalising of contact resistances at all the electrode-earth contacts.

A circuit diagram, illustrating the operation of the selector switch is shown in Fig.12. The testing principle is as follows:

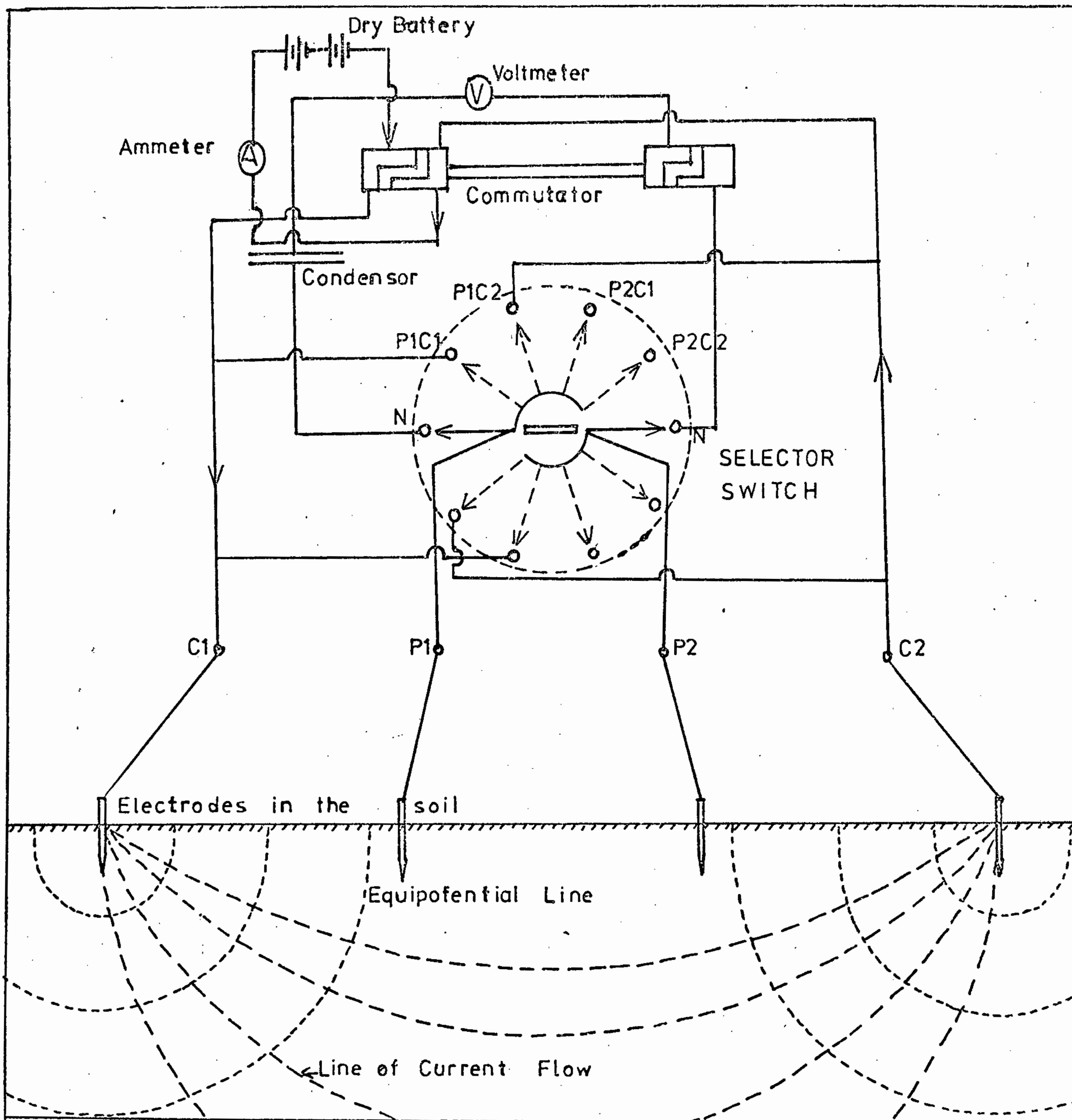


FIG. 12 - CIRCUIT DIAGRAM OF SELECTOR SWITCH ON THE GANE-ENSLIN RESISTIVITY METER

POSITIONS OF SWITCH

N	Operating - current from commutator to C1 and C2
P1C1	Test - current from C1 + P1 to C2
P1C2	Test - current from C1 to P1 + C2
P2C1	Test - current from C1 + P2 to P2
P2C2	Test - current from C1 to P2 + C2
C2o	Contact for electrode C2

(i) In position N, the operating position, current flows from the batteries to the commutator, where it is periodically reversed. From the commutator it flows through the C-electrodes into the soil. The current flowing in the soil is measured at ammeter A. The potential difference developed in the soil by this current is picked up by the P-electrodes from which the induced current flows to the commutator. Here it is reversed to form a direct current so that the potential difference can be measured, and the specific resistance of the soil be calculated. In practice a Wheatstone Bridge and null-point galvanometer is used.

(ii) For testing, the selector is now switched to position P1C1. Current now flows through C1 plus P1 to C2. The current is again measured on ammeter A.

(iii) The selector is now switched to position P1C2, and the current flows from C1 through the soil to C2 plus P1. The difference in the currents for positions (ii) and (iii) is a measure of the difference between the contact resistances of C1 and C2. By reducing the contact resistance at the electrode where the higher resistance is found (usually by hammering the electrode deeper into the soil) the contact resistances can be equalised.

(iv) The selector is now switched consecutively to positions P2C1 (current flows from C1 plus P2 through the soil to C2) and P2C2 (current flows from C1 through the soil to C2 plus P2). Because the contact resistances at C1 and C2 have already been equalised, the difference in current for positions (iii) and (iv) is a measure of the differences in contact resistances between

P1 and P2, and they can now be equalised. Through practice this procedure can be followed in a short time.

It must be noted that:

(a) The condenser C is by-passed during testing, and the commutator need not be operated during the time of testing.

(b) Should the switch accidentally remain in any position other than the N or operating position, no potential difference can be obtained, and no reading can be registered on the Wheatstone Bridge. The switch is therefore foolproof in operation.

Without this procedure it is practically impossible to interpret the results of depth probes where high surface resistivities are found. As example, depth probes done on Ezelklaauwpan in the Prieska District is shown in Fig. 13, showing the results before and after equalising contact resistances.

High surface resistivity was particularly troublesome where

(i) the granite yielded a coarse sandy soil as on Springbokvlei 232, Krugerspan 804, Frankvley 807, Rietkuil 226, Holland 109 and others,

(ii) calcrete occurred at the surface without soil-cover as on Blinkwater 628, Moorland 449, Beaufort 454 and others.

The Wenner configuration of electrodes was used throughout because of its simplicity and ease of operation:

(i) The specific resistance or resistivity is calculated by the simple formula $\rho = 2\pi a \frac{E}{I}$

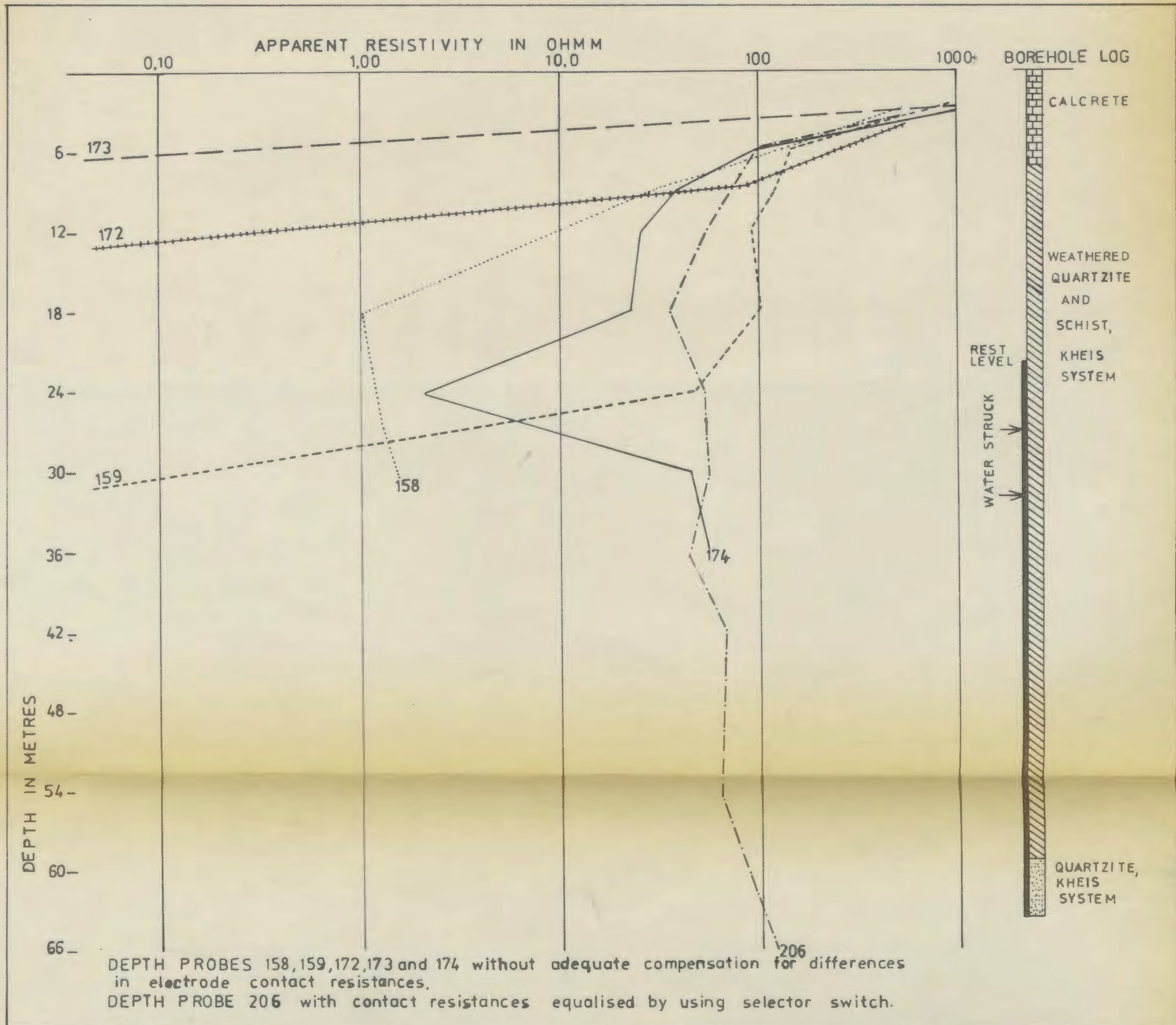


FIG.13 - DEPTH PROBES AT ONE POSITION ON EZELKLAAUW, PRIESKA DISTRICT,C.P. illustrating the effect of high and unequal electrode contact resistances.

where ρ = resistivity in ohm m

a = electrode spacing in m

E = potential difference between inside electrodes in volts

I = current through outside electrodes in amperes.

(ii) Because use was made of unskilled labour for spacing the electrodes, the separation between electrodes had to be in simple units, easily duplicated e.g. 1,2,3,6,9,12,15,18,24,30,36 m. In the Wenner configuration the distances between all the electrodes are equal.

(iii) For empirical interpretation in the field calculation is easy and quick, so that immediate decisions can be made about the best position for the next depth probe, the best site for a borehole, the depth to which the borehole must be drilled, etc.

The theory of horisontal layers of semi-infinite extent was used, and corrected for lateral effects (Enslin, 1948). For empirical interpretation it was assumed that the effective depth of current penetration was equal to a in the formula above.

The method of depth probing was always used i.e. readings started at a point with the electrodes close together along a straight line. The electrodes were moved progressively further apart, until a sufficient depth of penetration was reached to draw a graph from which depths to the required contacts could be interpreted.

Resistivity surveys usually comprised the following:

(i) A reconnaissance survey over a wide area to locate possible favourable areas for ground-water development.

(ii) Intensive surveys in the favourable areas to determine the best sites for boreholes.

Because outcrops are extremely scarce, and no surface indications of ground-water were found on the granite and Swaziland System, it was sometimes necessary to do depth probes right across a farm, from north to south and from east to west. For example on the farms Krugerspan 804, Groenvlei 64, Emmetsvalley 220, Frankfort 60, Moorland 449, and Ysterpan 66 the numbers of depth probes were 424, 223, 376, 195, 209, and 640 respectively, i.e. a total of 2 067 depth probes on six farms. In addition 2 477 magnetic stations were surveyed. Even this intensive survey failed to locate adequate supplies on Krugerspan 804, and only one each on Frankfort 60 and Moorland 449.

One of the more important applications of the resistivity method was the taking of readings at existing boreholes to correlate the specific resistance with the borehole log. Depth probes were done at more than 400 existing boreholes. By this means certain resistivities were correlated with specific formations. Some of the results are as follows:

Resistivity of weathered Archaean granite	less than 500	ohm m
Resistivity of unweathered Archaean granite	more than 1 000	"
Resistivity of weathered Swaziland rocks	less than 100	"
Resistivity of unweathered Swaziland rocks	100 to 1 000	"
Resistivity of turf or clay	10 to 50	"

Resistivity of dry sandy soil	5 000 to 10 000 ohm m
Resistivity of surface limestone or calcrete	150 to 500 "

5.2.2.1.3 ELECTRICAL BOREHOLE LOGGING

By lowering three electrodes in a borehole filled with water or mud, while a fourth electrode was attached to the casing or another convenient point at the surface, the resistivities were measured at different depths in a borehole. If the resistivity of the contact medium (water or mud) is constant for the whole depth of the borehole, the measured resistivities are in direct proportion to the resistivities of the formations traversed. If the electrode-separation is five to ten times the diameter of the borehole, the resistivity of the contact medium can be ignored. For more detailed work the electrode-separation is smaller, and the resistivity of the contact medium is measured by means of a unit cell. Different electrode separations in the same borehole can also be used to determine the resistivity of the contact medium relative to that of the rocks traversed. In the Rustenburg District it was almost impossible to do borehole logging in existing boreholes, due to the fact that all successful boreholes were equipped with pumping plants and all unsuccessful boreholes were filled up to preserve livestock from accidents. Borehole logging was done in newly-completed boreholes before they were equipped with pumping plants or filled up.

5.2.2.1.4 ELECTROMAGNETIC SURVEYS

The instrument used was the so-called "Pari", developed by Dr.

Guelke (of the University of Cape Town), and later on improved by Bellairs (Enslin, 1955). The circular method of taking readings, developed by Enslin (1955), was used. The alternating current used, developed a current of approximately 1 ampere in the earth at a frequency of approximately 5 000 cycles per second. This should give a theoretical effective depth penetration of 14 to 15 m (Jakosky, 1961) depending on the materials forming the subsurface. Tests were done on the Archaean granite on Laastepoort 840, Klipdrift 842, and Krugerspan 804, and on the Swaziland System on Groenvlei 64, Blinkwater 628, and Franksvley 807.

The results were not very encouraging, probably due to the depth to the ground-water reservoir, the shallow depth of effective penetration, and the absence of narrow steeply-dipping structures in which water could be found. In general the anomalies measured were small and irregular and could not be followed over long distances. On Klipdrift 842, where the granite occurred at a shallow depth, the readings were very irregular so that it was impossible to select definite structures. On Blinkwater Road Camp a very small anomaly was measured near the strong borehole yielding 5 m^3/h (Fig.14). Further tests will have to be made with improved instruments and perhaps different techniques to find out if this geophysical method can be used effectively in this area.

5.2.2.2 CAPE PROVINCE

Although tests were conducted with various types of instruments, geophysical surveys for the selection of borehole sites were done

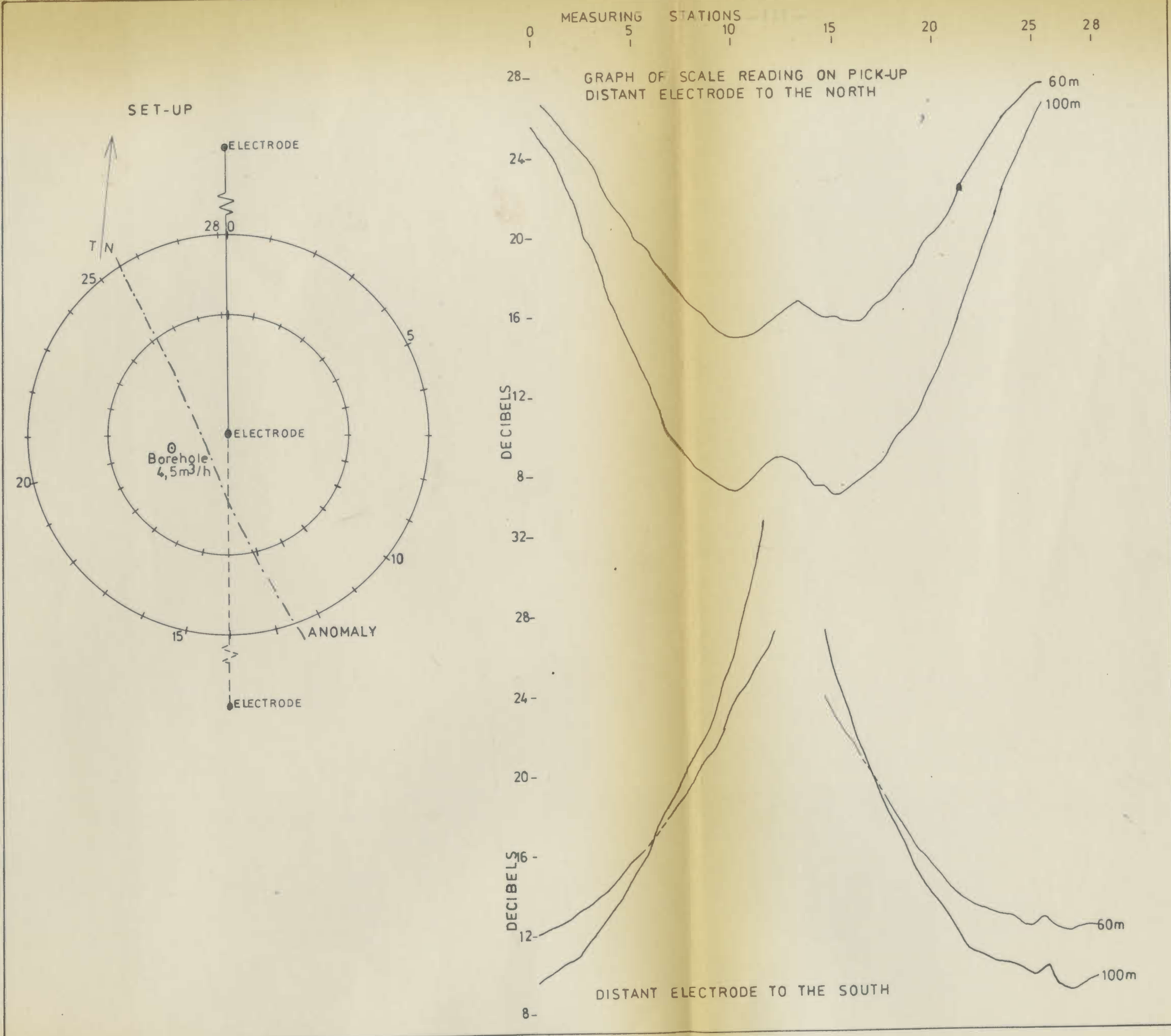


FIG.14 - ELECTRO-MAGNETIC SURVEY WITH THE CIRCULAR METHOD ON BLINKWATER 628, N.W.TRANSVAAL

by the same types of instruments as used in the Transvaal.

5.2.2.2.1 MAGNETIC

The same type of vertical variometer was used as in the Transvaal. Because outcrops are numerous, and structures or contacts could in many instances be determined approximately by means of photo-geology, it was seldom necessary to survey long magnetic traverses to get an indication of the sub-surface geology.

Several long magnetic traverses (a total of 1 860 magnetic stations over a total distance of 438 km) were confined primarily to the Transvaal System and therefore fall outside the scope of this thesis. They were used as an aid in unravelling regional structures. South-west of Prieska two long traverses were surveyed across the Doornberg Fault, and the position of the fault and of younger shear or fault-zones in the granite, which were mineralised, could be deduced from the magnetic anomalies. A total of 1 060 magnetic stations were surveyed over a distance of 32 km.

The magnetometer was also used over rocks having remanent magnetism differing appreciably from the regional magnetism. It was mostly used for the locating of dykes covered by sand, calcrete, soil or alluvium, and their contacts with the rocks into which they were intruded. It was, however, also used successfully for determining the maximum depth of weathering in a dolerite sheet on Knapsak, Kenhardt District; and in Ongeluklava on Waverley, Hay District. The relative depth of weathering in Namaqualand gneiss could be approximately determined on Kharkhams, Namaqualand, so that the number of electrical resistivity measurements, which are much more time consuming, were reduced to a minimum. The trace of the Doornberg Fault could be determined by the difference in the remanent magnetism on opposite sides of the fault. Some shear-zones were subsequently ferruginised and can therefore be traced by the magnetometer e.g. on Louis in the Prieska District, where a shear-zone, probably a continuation of the zone on which copper is found on Vogelstruisbult, yielded a strong anomaly along the main road to Van Wyksvlei.

5.2.2.2.2 ELECTRICAL RESISTIVITY

The same instrument and the same methods were used as in the Transvaal. On the granitic rocks , whether granitised sediments, granulite, paragneisses, grey gneiss or adamellite, resistivity surveys were used to determine the relative depths of weathering.

Over large areas in the Prieska, Kenhardt, and Namaqualand Districts the Bushmanland Plateau is found. There is very little surface relief and a covering of sand, soil or calcrete is ubiquitous. Although by a study of the topography and photo-geology certain portions of a farm could be eliminated as possible areas in which economical yields of ground-water could be found, there often remained hundreds or thousands of hectares in which water could occur. Often no structures could be seen or inferred, valleys being broad and ill-defined with very low gradients, and the vegetation being xerophytic and giving no indication of possible accumulations of ground-water. In these cases the same methods were followed as in the Transvaal viz. reconnaissance surveys over large areas, and intensive investigation of the most promising areas delineated by the resonnaissance survey.

Under special conditions it was possible to determine the contact between formations or lithological units and to calculate approximate dips. An example is the contact between tillite of the Dwyka Series and quartzite of the Kaaien Series, which could be determined where the Dwyka tillite was still semi-weathered on Brandboom and Maraisdraai in the Prieska District. The dip of the quartzite could be calculated and boreholes sited to strike the quartzite aquifer at the correct depth below the ground-water rest level, after passing through solid tillite.

The trace of faults or shear-zones could be determined under cover where the resistivity of a brecciated zone differed appreciably from that of the surrounding rocks, and the width of brecciation was comparable to or greater than the thickness of the cover. On the farm Melkboombakke in the Kenhardt District a brecciated zone was seen on one side of a large sanddune but could not be located in the flat on the other side, where water was required. Several failures were drilled in the vicinity. The shear-zone was located by a traverse of resistivity depth probes spaced close together, and a successful borehole was drilled.

Another parameter which could be determined from resistivity surveys was the relative quality of ground-water, provided the necessary conditions were present or could be deduced. A very good example is the work done on salt pans in the Prieska and Hopetown Districts, just outside the area under discussion (Schumann, 1962). The surfaces of the pans are level and the geological succession consisted of homogeneous shale and tillite of the Dwyka Series with horizontal bedding-planes, covered by clay. By careful layout of constant separation traverses, the small differences in resistivity could be measured at a slightly greater depth than the depth to the water table. These differences were due to differences in the quality of the water, and several successful boreholes and wells for the production of brine were sited on a number of pans by this method.

As in the Transvaal, measurements at existing boreholes yielded information of prime importance for correlating resistivity with depth of weathering and yield, especially where detailed logs of the boreholes were available. Resistivity depth probes were taken at several hundreds of boreholes in the area under consideration.

5.2.2.2.3 ELECTRICAL BOREHOLE LOGGING

The same method was used as in the Transvaal. In this area even less boreholes were available for measurements due to the fact that even a smaller percentage of boreholes yielded water, and boreholes with very small supplies were equipped with windmills as soon as possible after completion.

5.2.2.2.4 ELECTRO-MAGNETIC METHODS

Investigations were done by J.R. Vegter in 1953 (unpublished report) with the Pari-instrument on seven farms between Kakamas, Kenhardt and Pofadder. This is an area in which very few successful boreholes exist. Readings were taken at several existing boreholes, successful and unsuccessful, some on outcrops of quartz-breccia. Three boreholes were drilled on sites selected on "Pari"-anomalies. Of these two were dry and one yielded 7,68 m^3/h, which is a very good supply for this area. The circular method (Enslin, 1955) was used for all the surveys.

During 1970 an improved type of electro-magnetic instrument was used to the west of Prieska in the Kheis System and granite. Use was made of the linear method (Vegter, 1962) with the grounded electrodes 400 to 800 m apart. This method was used as a reconnaissance survey to determine the relative depths of weathering in the granite over a large area in a much shorter time than was possible with resistivity depth probes. Promising areas were more intensively investigated by the resistivity method. Very good supplies were obtained for the new copper mine near Prieska, ranging between 10 and 15 m^3/h. Several shear-zones and faults were also traced by this method on other farms in the vicinity.

5.2.3 STATISTICS

By the use of statistics of existing ground-water supplies the selecting of borehole sites is facilitated, the amount of geological and geophysical observations reduced, and the probability of finding a suitable supply increased.

5.2.3.1 TRANSVAAL

During the survey of this area all the available information of more than one thousand boreholes was collected. Geological logs yielded information about the type of rock in which water was struck at different depths. Hydrological information included the depth at which water was struck, the yield, rest level, and the quality of the water. By geophysical surveys the geology was correlated with the hydrological information, and with the resistivity and magnetism of the formations.

Geophysical surveys were carried out at four hundred existing boreholes. Usually three to five depth probes were done at or near a borehole so that the geological structure could be determined. It was sometimes necessary to do depth probes with the line of electrodes in different directions due to anisotropy of the formations, especially in the Swaziland System. These geophysical surveys were often the only means of finding out why a specific borehole was a failure or a success.

By evaluating the above information statistically, it was possible to delineate certain areas, specific topographical conditions, geological formations, and certain geophysical parameters which provide a high degree of probability for the finding of groundwater. By the use of statistics the selection of borehole sites could be done much more quickly and with greater assurance of success than without its use. Various methods of evaluating the statistical information will be illustrated in the succeeding chapters.

5.2.3.2 CAPE PROVINCE

Information from several thousands of boreholes were collected in this area, more than 2 500 from the Kenhardt District. In this district boreholes have been drilled on practically every farm and subdivision of a farm, sometimes as many as hundred or more (e.g. Rietfontein), and more boreholes are added as older boreholes dry up, or the farm is camped into smaller units. Although borehole records are usually compiled by persons without any geological training, requiring careful evaluation of the evidence, analyses of these records and correlation with geological and geophysical evidence collected in the field, yield useful information about the occurrence of ground-water.

The same procedure as described for the Transvaal was used, and the same correlations made. Predictions could be made about the probability of striking adequate supplies of ground-water in a certain area, or in a certain rock-type or formation, the probable depth to the ground-water, and the expected yield and approximate quality.

5.2.4 TOPOGRAPHY

As mentioned before, the effect of topography could be ignored in the Transvaal, and all the borehole sites were selected geophysically.

In the Cape Province topography was of major importance for the control of infiltration of rain-water, and as a result, for the selection of borehole sites. In these arid regions water can only infiltrate down to the ground-water reservoir:

(i) Where outcrops or sub-outcrops of rocks with bedding-planes or secondary structures are found, along which water can percolate; or along the contact of such rocks with the overlying calcrete, wind-blown sand, soil or alluvium. These structures or contacts must be open so that percolation can be fast, and it must extend below the range of tree roots.

(ii) In the larger laagtes with low gradients and porous calcrete or sandy soil at the surface. Due to the slow rate of movement of water after a rainstorm the water can percolate into the porous formation, and may eventually reach the ground-water reservoir.

(iii) Where water is collected in dams or pans. Pans are especially numerous on the Bushmanland Plateau, and small earthen dams have been constructed on nearly every farm. In the broad shallow valleys small excavation dams ("gatdamme") are numerous. Especially on porous formation infiltration from these pans and dams is rapid and effective.

(iv) By artificial recharge in a borehole or well into a confined aquifer. The Municipality of Williston diverted water from the Zak River into a "saaidam", and then pumped it into a shallow furrow in a small dam near the municipal boreholes. The dam is in a closed basin in a dolerite sheet, and the material in the dam was a coarse porous sand in which the water infiltrated at a fast rate. The water was pumped out again by means of the municipal boreholes for town use, without evaporation loss during storage for a period of twelve months or longer.

A unique method of utilising impounded water is used by B.F.Snyman on his farm Lerato in the Kenhardt District. A large gatdam was constructed in a small patch of Dwyka shale in an otherwise stony area in the granite. The dimensions of the dam are approximately 10 x 20 x 30 m and long furrows diverted the run-off on the stony soil surrounding the dam, into the 10 m deep dam. After the initial filling and sealing of the interior by mud and silt and some artificial filler, evaporation and infiltration amounted to a depth of approximately 3 m per year. Water was pumped out when needed for stock-watering by a small windmill on the edge of the dam. The full supply is adequate for supplying all the livestock that can be grazed on the farm with water for one and a half to two years.

5.2.5 VEGETATION

5.2.5.1 TRANSVAAL

As previously stated certain types of trees were associated with certain formations and could, therefore, be used as indicators for the locating of possible ground-water supplies. Others, including <u>rhus</u> and <u>grewia</u> spp. indicated the presence of shallow water, but this was sometimes due to a small perched water table above a clay lens, and did not necessarily indicate an economic supply.

Dense growths of trees often indicated an old drainage line which could be traced on air photos. Certain types, as the knoppiesdoring, prefer deep soil, and where they occurred between others with a shallow root system, they indicated deeper weathering, where water could be expected.

5.2.5.2 CAPE PROVINCE

"Bosare" (lines of bush or trees) were regarded as infallible indicators of aquifers or aquicludes. Usually a denser growth of trees or bush were found on secondary structures such as joints, shear-zones, brecciated zones, faults, and thin sandstone, conglomerate or other horizons which were more permeable than their surroundings; or the bosaar could be a dyke, silicified shear-zone or fault, or a similar aquifuge arresting the flow of ground-water.

Certain trees, such as the deep-rooted kameeldoring (acacia giraffe) prefer deep sandy soil, and a concentration of these trees or a line of them indicated the presence of ground-water, or a structure along which ground-water occurred. Martin (1961) mentioned that lines of such trees break off or peter out where the ground-water rest level drops below 30 m in the sand of the Kalahari in the eastern portions of South West Africa. Acacia karoo trees were found only along rivers and laagtes in which ground-water was near to the surface, or where surface flow occurred regularly. Rhus lancia and boscia albitrunca were usually found in shallow and stony soil where economic supplies could not be expected.

Due to the large variations in topography, climate, geological formations and structure, depths to ground-water reservoirs vary between wide limits. Some of the trees have been adapted to a deep root system of 20 to 50 m. In one instance on the farm Sanddam, Kenhardt District, roots of a small swarthaak (acacia detinens) of approximately 4 m high, clogged the borehole cylinder at a depth of 81 m.

Unfortunately, due to human occupation, much of the area has been stripped of all, or nearly all, trees.

6. THE OCCURRENCE OF GROUND-WATER IN THE BASEMENT SYSTEMS

6.1 THE SWAZILAND SYSTEM IN TRANSVAAL

6.1.1 DISTRIBUTION

6.1.1.1 VEGETATION

Because outcrops of rocks correlated with the Swaziland System were found only on a few widely-separated farms as described in chapter 3.2.1.1, very little direct evidence of the distribution of this formation has been found. From the type of soil and/or vegetation it was sometimes possible to deduce the presence of Swaziland rocks at a relatively shallow depth. Black turf soil occurred on basic rock-types associated with the Swaziland System. The knoppiesdoring (acacia nigrescens) was found in park-like abundance on clayey and calcareous soil weathering from schist and certain sediments. Another acacia, locally called "mashouka", formed thickets on rich clayey soil derived from the Swaziland System. Several other members of the acacia family preferred the more fertile soil derived from the Swaziland System to the acidic sandy soil on the granite and gneiss.

6.1.1.2 MAGNETIC SURVEYS

As described in chapter 5.2.2.1.1 the anomalies calculated from regional magnetic surveys could be used to deduce the presence of rocks belonging to the Swaziland System. On the accompanying geological map (Fig. 15) use was made of this evidence to delineate areas in which this system may occur under a covering of soil, sand or calcrete. This map was compiled from all the available evidence described in this chapter. It is incomplete because more detailed information is lacking. Some of the granite on this map may be granitised sediments of the Swaziland System. Magnetically all the granite had the same normal reading, and no division was possible.

6.1.1.3 BOREHOLE RECORDS

Most of the information about the rock-types in the Swaziland System was derived from boreholes, and this information was also used for the geological map (Fig. 15). Because the boreholes were all drilled by percussion drills, unweathered rock was usually ground to coarse or fine sand with occasionally larger chips, so that it was often impossible to recognise the original rock-type from which the sample was obtained. Although the grade of metamorphism was not high, the smallness of the samples hampered identification.

Almost all of the samples were schistose or quartzitic. The most abundant minerals were quartz, sericite, chlorite, hematite, specularite, felspars (the most abundant being plagioclase), amphiboles, pyroxene, calcite and various clays. It was deduced that the minerals were derived from the following rock-types:

(i) Quartzite, sometimes recrystallised and sericitised or chloritised, and often ferruginous. Felspar, or clay-minirals derived from the felspar, were usually present. The original rock might have been felspathic sandstone or arkose, or a subgraywacke.

(ii) Several types of schist which were probably derived from shale or the more shaly quartzite and arkose. Some samples were still recognisable as shale, due to ferrugination and sometimes silification. Most of the shale and mudstone must have been decomposed to clay. Some of the more shaly sandstone has been altered to phyllite.

(iii) Limestone or marl, probably to a certain extent altered to amphibole rock.

(iv) Lava, partly altered to amphibolite and granulite.

(v) Gabbro and similar rock-types. Whether these rock-types were alteration products of volcanic rocks, or dyke-rocks could not be determined due to the scarcity of samples.

6.1.1.4 RESISTIVITY DEPTH PROBES

By correlation of the results of resistivity depth probes at existing boreholes, in which the rocks were recognised as belonging to the Swaziland System, with depth probes at other places, it was sometimes possible to deduce the area over which these rocks were to be found. Some of the boundaries between sediments or metamorphics and granite were derived from these surveys.

6.1.2 HYDROLOGICAL PROPERTIES

Due to the degree of deformation and metamorphism to which rocks of the Swaziland System had been subjected, there did not seem to be any primary hydrological properties in these rocks. It is surprising that there is an almost complete lack of surface relief which would usually be associated with the wide variety of rock-types in the Swaziland System, as seen in the Eastern Transvaal and Swaziland. The only hydrological properties are due to secondary structures and weathering. Due to the uniform deep cover of soil, alluvium and calcrete, the ubiquitous cover of vegetation, and the lack of surface relief there was no observable difference in the hydrological properties of the different rock-types of this system, and they are treated as a unit. This does not mean that the percentage of success or the yield was identical in all the different rock-types, as will be discussed later.

The depth of weathering, which was deduced from the resistivity depth probes, was caused by differences in petrological composition, contacts between different rock-types, folding, faulting, shearing, jointing and other linear structures, or a combination of these processes. It was impossible to deduce any of these prosesses, and the depth of weathering was used as the primary control in the interpretation of the hydrological properties and for the selection of borehole sites.

6.1.3 STATISTICS

6.1.3.1 BOREHOLE RECORDS

Logs of a total of 549 boreholes could be traced. On Fig. 16 the depths of the boreholes are given as a cumulative graph of

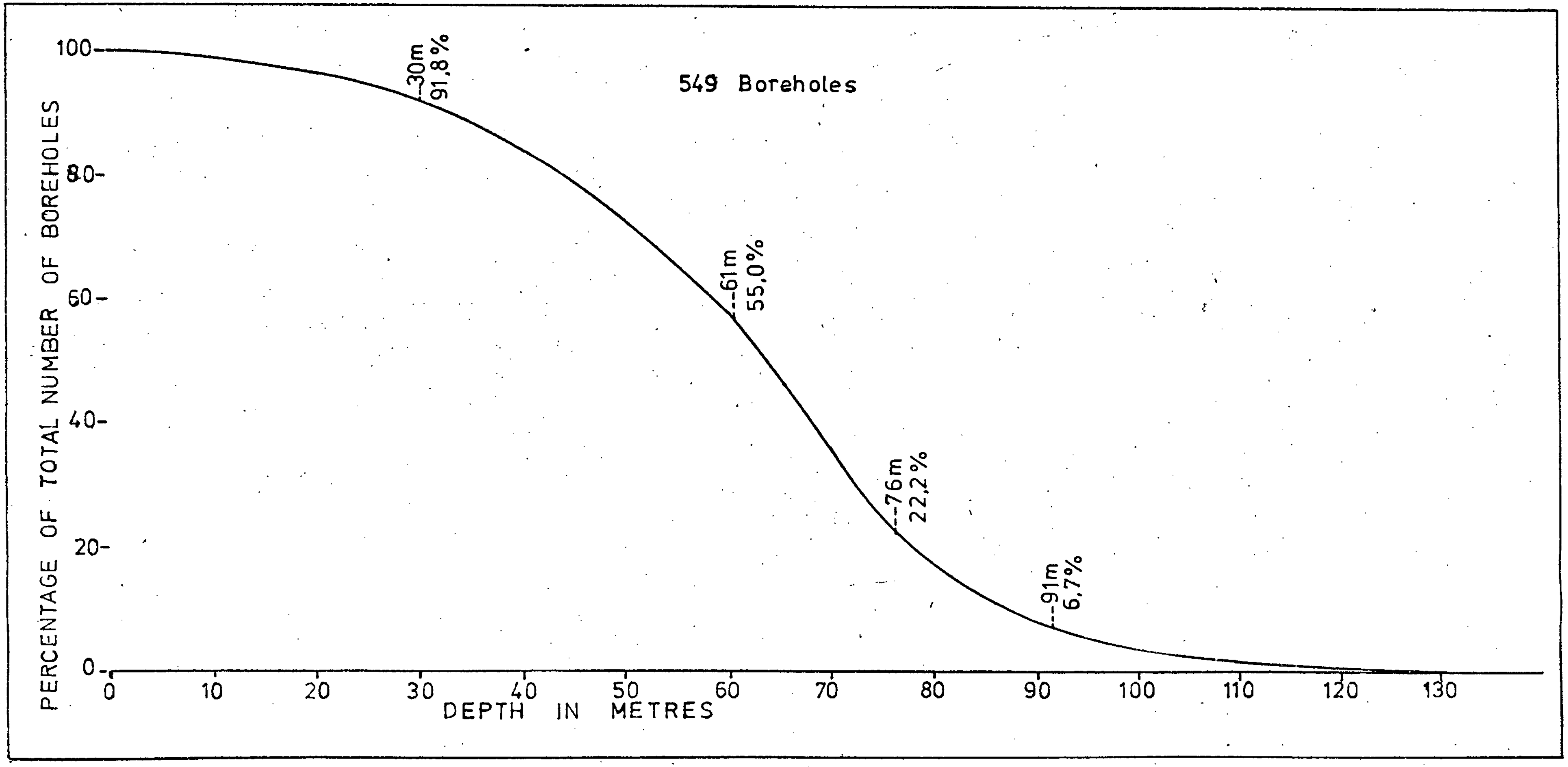


FIG. 16 - CUMULATIVE GRAPH OF PERCENTAGE OF TOTAL NUMBER OF BOREHOLES EXCEEDING A GIVEN DEPTH, SWAZILAND SYSTEM, N.W. TRANSVAAL.

percentage of boreholes exceeding a given depth. Ninety-one per cent of the boreholes exceeded 30 m, 55 per cent exceeded 61 m, and only 6,7 per cent 91 m. A cumulative graph of yield as a function of the percentage of the total number of boreholes against yield (Fig. 17), shows that only 32 per cent of the boreholes were successful, and only 25 per cent yielded more than 1 m^3/h. A cumulative graph of the depth at which water was struck (Fig. 18) shows that 90 per cent of the water was struck at depths between 30 and 91 m, and 83 per cent shallower than 73 m.

A histogram of the depths at which water was struck in 361 boreholes yielding water, and in 211 successful boreholes included in the previous group, is shown in Fig. 19. The principal difference between the two histograms is that there is a smaller variation between the intervals 30 to 46 and 46 to 61 m for the successful boreholes than for the total number of boreholes. Eighty-six per cent of the successful boreholes yielded water before a depth of 61 m was reached, and 68,7 per cent between 30 and 61 m.

The rest levels in the boreholes are shown in the same figure as another histogram. Ninety-six per cent of the 299 boreholes had rest levels shallower than 61 m and 67 per cent shallower than 46 m.

6.1.3.2 RELATION BETWEEN DEPTH OF WEATHERING AND DEPTH AT WHICH WATER WAS STRUCK

It was found from the analysis of 131 boreholes which were personally inspected or in which borehole logging was done, that

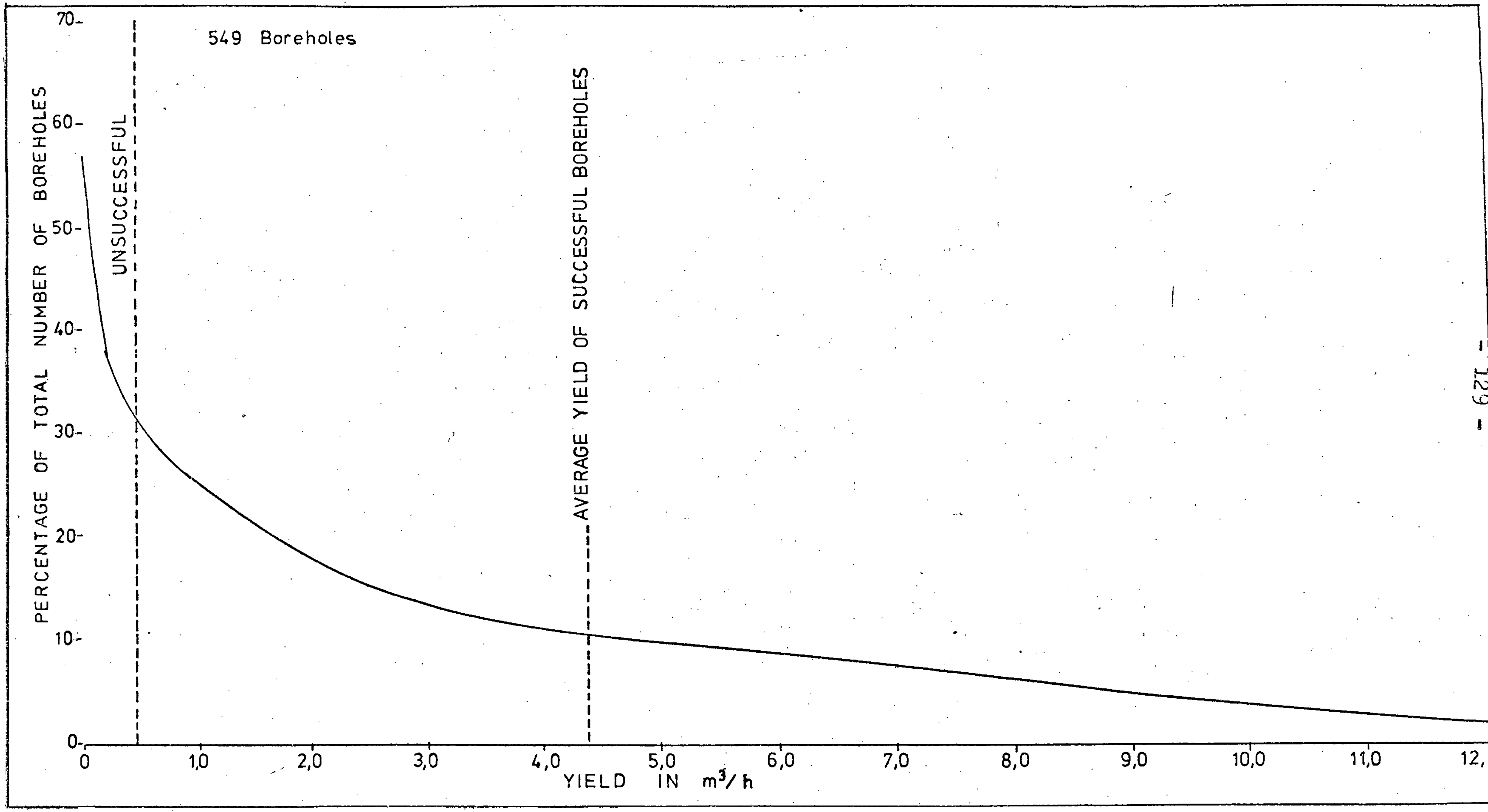


FIG.17 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF TOTAL NUMBER OF BOREHOLES, SWAZILAND SYSTEM, N.W. TRANSVAAL.

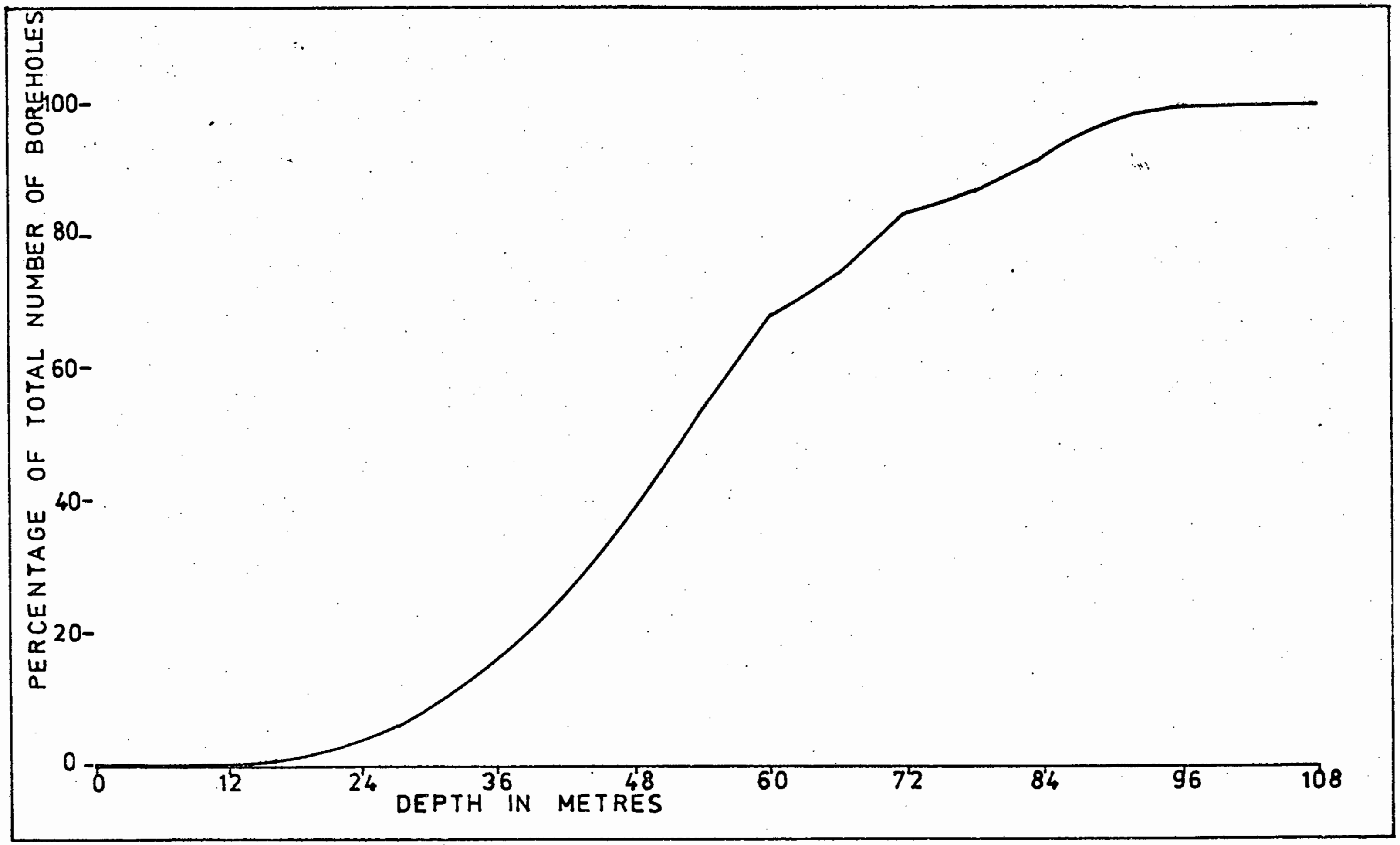


FIG.18 - CUMULATIVE GRAPH OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE TOTAL NUMBER OF BOREHOLES, SWAZILAND SYSTEM, N.W.TRANSVAAL.

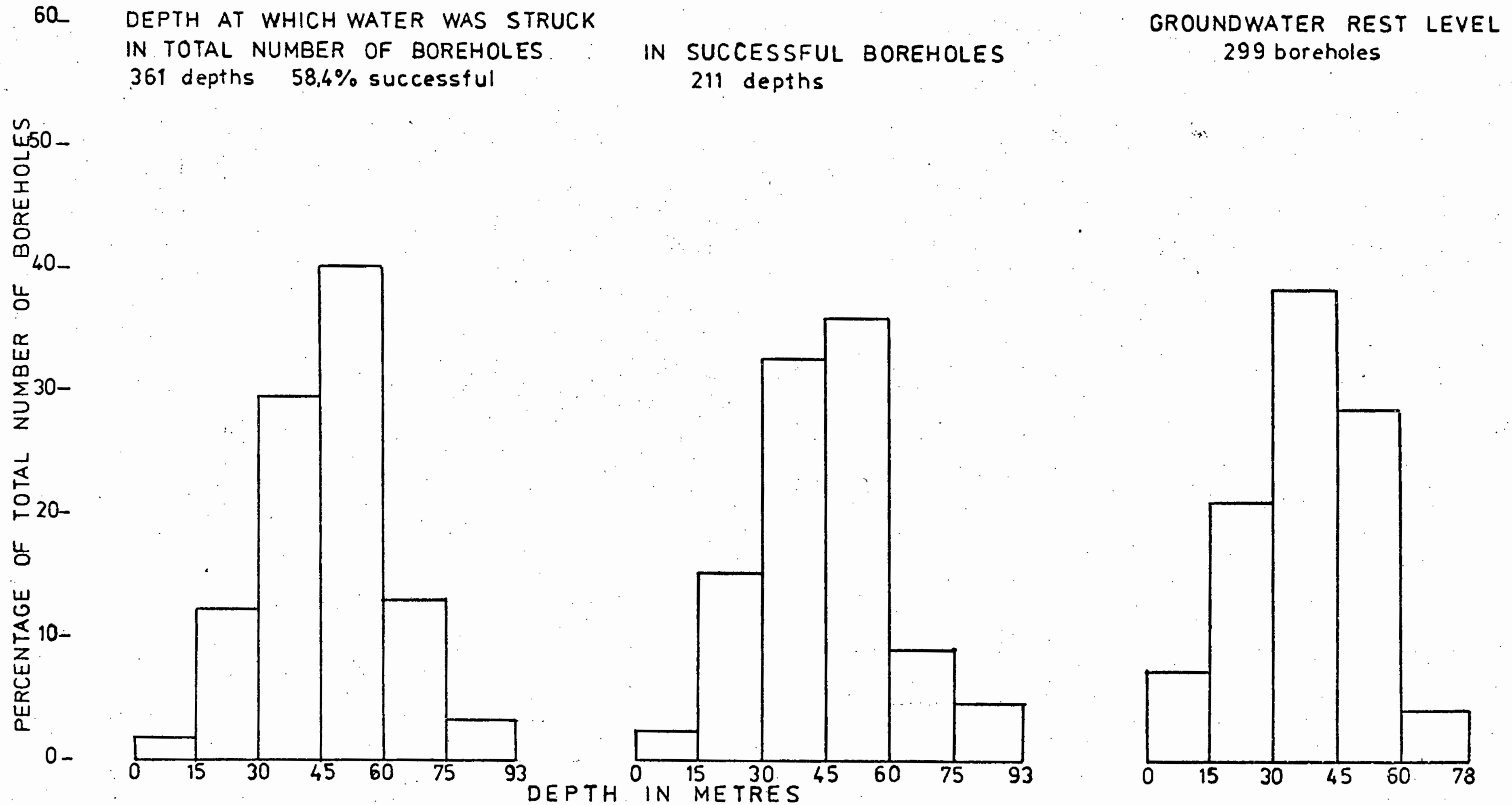


FIG. 19 - DEPTHS AT WHICH WATER WERE STRUCK AND GROUNDWATER REST LEVELS, SWAZILAND SYSTEM, N.W. TRANSVAAL.

weathering varied between depths of 30 and 61 m in 66 per cent of them, and in 16 per cent it extended to a greater depth. The largest percentage of boreholes with adequate yields had depths of weathering between 46 and 76 m. No successful supplies were found in the few boreholes with weathering deeper then 76m, probably due to the clayey nature of the weathering and the closing of secondary structures by the pressure of the overburden.

In 72 per cent of the successful boreholes water was struck between 10 m shallower and 10 m deeper than the depth of weathering, the optimum range of success being within 3 m deeper or shallower than the depth of weathering. A histogram (Fig. 20) illustrates the distribution of the depth at which water was struck relative to the depth of weathering.

6.1.3.3 RESISTIVITY DEPTH PROBES

An analysis of the resistivity depth probes at 158 boreholes drilled in the Swaziland System rocks is shown as a graph in Fig. 21(a). The resistivity is calculated by the asymptote of the apparent resistivity at the depth of a change in slope of the resistivity-electrode separation graph as described by Enslin (1963). Because of the rather sharp maximum of yield and percentage of successful boreholes at a resistivity of 60 ohm m, the deduction that the hydrological properties of all the rock-types can be treated as a unit, is vindicated. The percentage of successful boreholes was however, still less than 50 per cent for a resistivity of 60 ohm m. Although the yield and percentage of

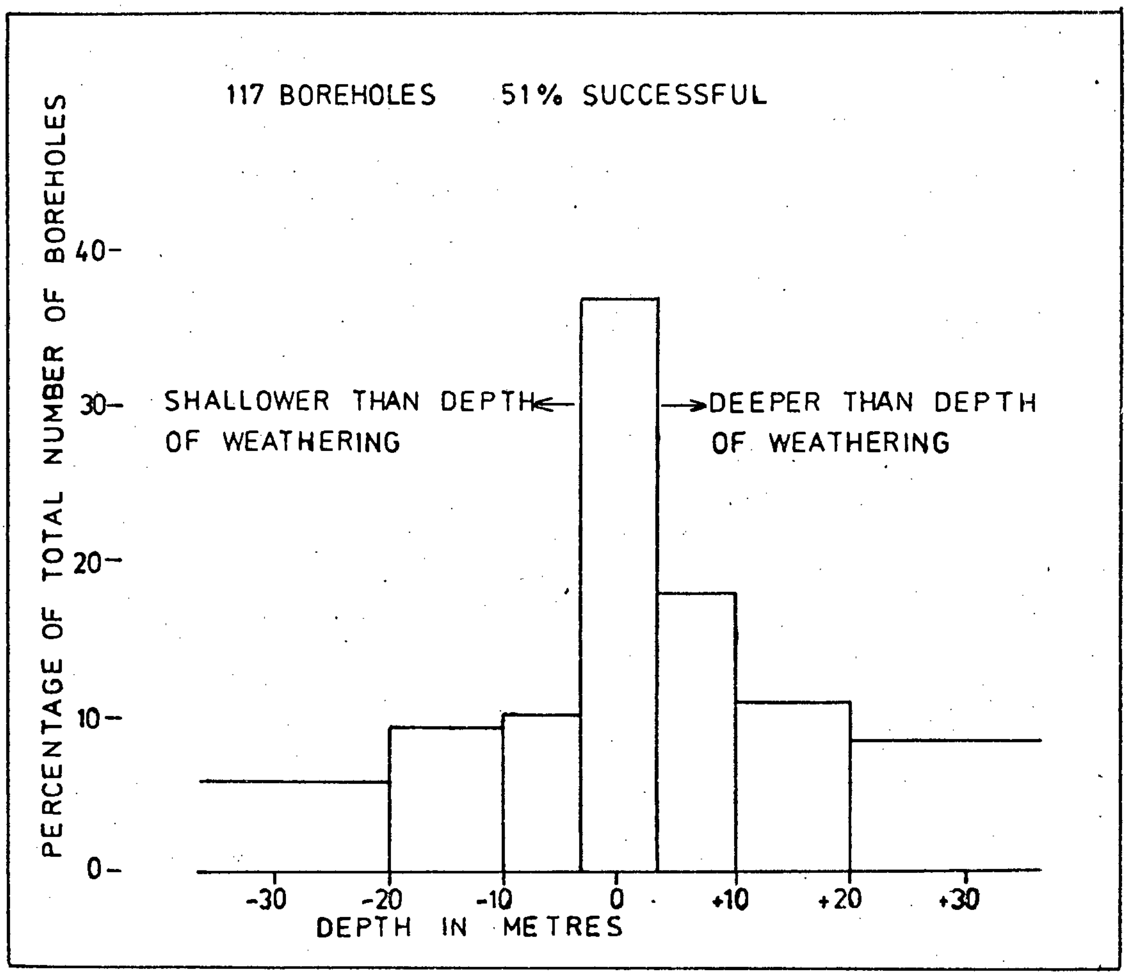


FIG. 20 - DEPTH AT WHICH WATER WAS STRUCK RELATIVE TO THE DEPTH OF WEATHERING, SWAZILAND SYSTEM, N.W. TRANSVAAL.

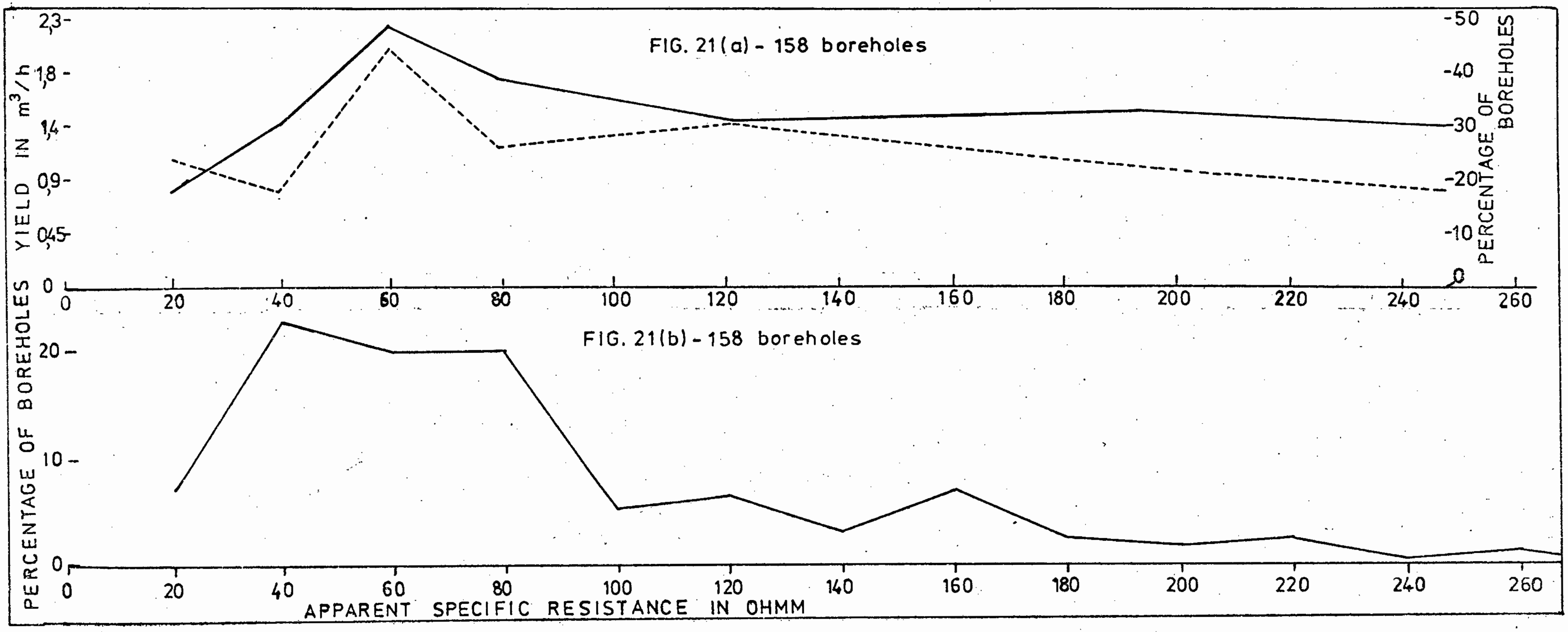


FIG. 21 - (a) SMOOTHED GRAPHS OF YIELD AND PERCENTAGE OF SUCCESSFUL BOREHOLES AS A FUNCTION OF APPARENT SPECIFIC RESISTANCE AT THE GROUNDWATER REST LEVEL.
(b) PERCENTAGE DISTRIBUTION OF BOREHOLES RELATIVE TO APPARENT RESISTIVITY.
SWAZILAND SYSTEM, N.W. TRANSVAAL.

successful boreholes decreased sharply at resistivities of less than 60 ohm m, there was appreciable scatter at higher resistivities, probably due to the quartzitic sediments which yielded water from narrow joints and other narrow secondary structures. One borehole on the western border of Kalabaspan 801 yielded 11 m^3/h from quartzite with a resistivity of 250 ohm m at the water table. The borehole was situated near a laagte below a small dam. Unfortunately the number of boreholes in which resistivity at the water level was higher than 90 ohm m, was small, so that the deductions for higher values of resisitivity were not reliable. This explains the irregular trend of the graph for this range.

The average yield of 2,18 m^3/h at a resistivity of 60 ohm m is a very low optimum yield. The optimum yield of 1,53 m^3/h at 140 ohm m is derived from too small a number of boreholes to be reliable. The percentage distribution of boreholes against resistivity is shown in Fig. 21(b). Sixty-three per cent of the boreholes had resistivities between 30 and 90 ohm m, and this range is therefore the only one from which reliable deductions can be made.

6.1.3.4 ELECTRICAL BOREHOLE LOGGING

The results from electrical borehole logging differed very much from the deduction above. The resistivities measured in the boreholes at the water levels were that of semi-weathered rock. Due to the ubiquitous covering of thick soil and weathered rock with low resistivities, the apparent resistivity at this depth as measured by depth probes, was very much lower, because it was a sum of the resistivities from the surface to the water level. Resistivities of up to 8 000 ohm m were recorded. From a total of 53 boreholes, only 12 (22,6 per cent) had apparent resistivities of less than 100 ohm m at the water level.

Of the 25 boreholes (47,2 per cent of the total) with apparent resistivity lower than 400 ohm m, 40 per cent were successful with an average yield of 1,2 m^3/h. Of the rest of the boreholes (52,8 per cent) only three (10,7 per cent) were successful.

Although the resistivities at the ground-water rest level were unexpectedly high, most of the boreholes that yielded water had weathered formation at this depth. A graph of the apparent resistivities against yield and percentage of success is shown in Fig. 22(a), and the cumulative percentage distribution of the boreholes over the range of resistivities in Fig. 22(b). It is obvious that even in the quartzitic sediments a certain degree of weathering is necessary before ecomonic yield of ground-water can be extracted. The three successes in boreholes with high specific resistance at the water level are probably due to open joints in otherwise unweathered formations. No boreholes in which the specific resistance at the water level was higher than 1 000 ohm m, were successful.

6.1.4 SELECTION OF BOREHOLE SITES BY MAGNETIC AND ELECTROMAGNETIC METHODS

A certain horizon (perhaps several horizons) in the Swaziland

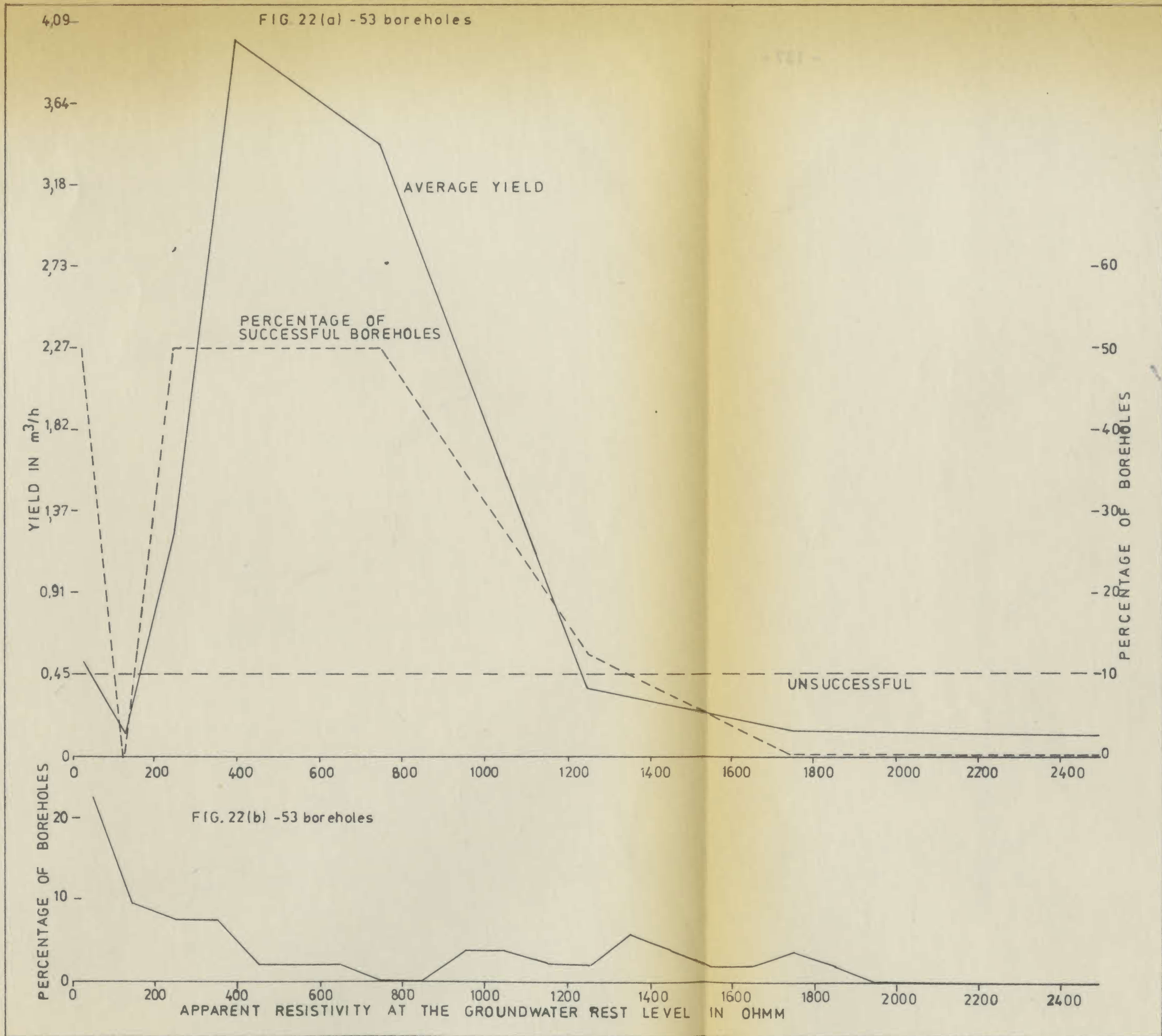


FIG. 22 - (a) YIELD AND PERCENTAGE OF SUCCESSFUL BOREHOLES AS A FUNCTION OF THE RESISTIVITY AT THE GROUNDWATER REST LEVEL AS DEDUCED FROM BOREHOLE LOGGING.
(b) PERCENTAGE DISTRIBUTION OF BOREHOLES RELATIVE TO APPARENT RESISTIVITY. SWAZILAND SYSTEM, N.W. TRANSVAAL.

System was strongly magnetic and could be traced by magnetometer even beneath a thick cover of soil and calcrete or weathered material. On the farms Blinkwater 628 and Ysterpan 66, such an anomaly of 3 600 to 6 600 gammas was traced. Water was found in a narrow zone, precisely delineated by the magnetic anomaly. Strong supplies were found in boreholes drilled for the road camp on Blinkwater 628 and on the farm Ysterpan 66 on sites selected along this zone.

This zone was also investigated by means of the "Pari" electromagnetic instrument with a frequency of 5 000 cycles per second, using the circular method (Enslin, 1955). The water-bearing zone could be detected, probably at the limit of effective depth of penetration, as a broad and not well-defined zone. A plan and graph of a set-up with the circular method at the borehole of the road camp are shown in Fig. 14. The anomaly was well-defined on the south side of the borehole, but vague on the north side. The conductive zone passed very close to the borehole, and was, therefore, due to the ground-water and not to the magnetic quartzite.

6.1.5 EFFECT OF TOPOGRAPHY, VEGETATION AND SOIL COVER

Because recharge of ground-water takes place by infiltration of rain-water, the topography, vegetation and soil cover should have a significant effect on the yields of boreholes. A number of boreholes selected by the Geological Survey were analysed for these parameters, and the results are shown in the accompanying histograms on Fig. 23:

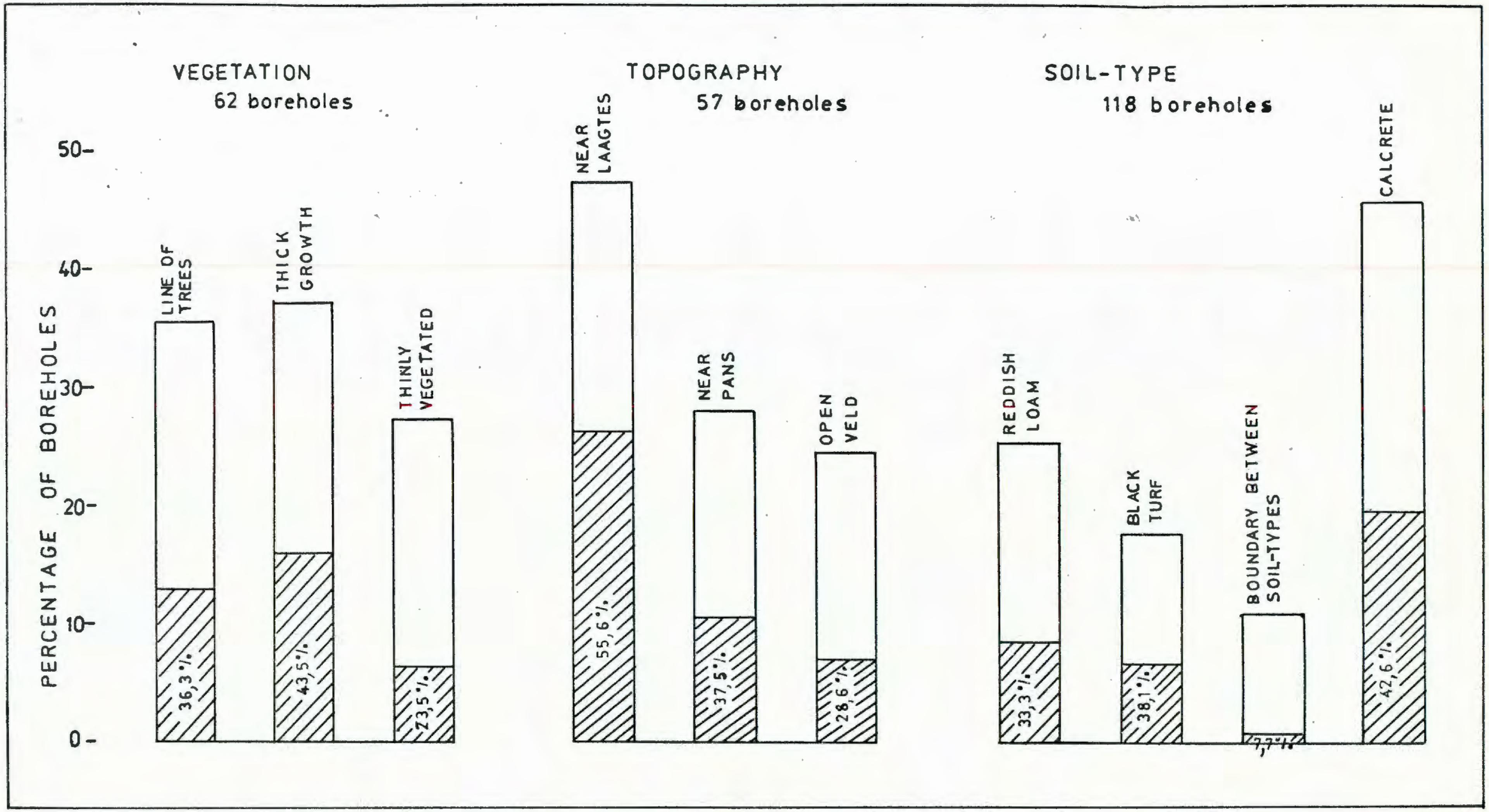


FIG.23 - HISTOGRAMS OF PERCENTAGE OF BOREHOLES IN DIFFERENT TYPES OF VEGETATION, TOPOGRAPHY AND SOIL; AND THE PERCENTAGES OF SUCCESSFUL BOREHOLES IN EACH TYPE. SWAZILAND SYSTEM, N.W.TRANSVAAL. (Successful boreholes shaded).

(i) Most of the boreholes were drilled near laagtes, of which 55 per cent were successful. Near pans 37,5 per cent were successful, whereas boreholes drilled where no topographical feature was visible, yielded 29 per cent of success.

(ii) Nearly 73 per cent of the boreholes were drilled along lines of trees or where there were concentrations of large trees. The results at these two types of vegetal cover did not differ very much, and approximately 40 per cent of the boreholes were successful. In those areas where the vegetation was monotonous and open, only 23,5 per cent of the boreholes were successful.

(iii) There was very little to choose between black turf or more sandy soil at the surface, as far as successful boreholes were concerned, probably due to the local extent of the turf soil. In an experiment on De Put near Northam on the Transvaal System (unpublished report by the author), where an earthen dam was constructed in a laagte, it was found that the turf loses its ability to absorb water within an hour after rain. Optimum infiltration occurred on the red sandy soil, and the contact with the turf served as the route along which the water percolated to the ground-water reservoir.

Due to its greater permeability, calcrete is a good aquifer. Of the 118 boreholes in which the surface cover was analysed, 45,8 per cent had calcrete from a depth of 0,3 to 0,6 m with a minimum thickness of 3 m and a maximum thickness of 50 m.

Of these boreholes 42,6 per cent were successful, which is appreciably higher than the 29,7 per cent of success in the rest of the boreholes.

6.1.6 EFFECT OF DIFFERENT ROCK-TYPES

Because of the limitations mentioned in chapter 6.1.1.3, and the inaccuracies of borehole logs, it was sometimes a question of intelligent guesswork to decide what type of rock was found at the level at which water was struck. Nevertheless it was decided to classify the rock on broad lines as:-

(i) Quartzitic sediments. This consisted predominantly of quartzite, ferruginous quartzite and arkose, with subordinate bands of shale and slate.

(ii) Schist. All rocks with a dominant schistose structure, and described by the driller as "schist" in the borehole log.

(iii) Igneous and metamorphic rocks. These included all rocks recognised as lava or amphibolite, gabbro, etc., and rocks described by the drillers as "diabase", "norite" or "dolerite".

Of the 541 boreholes included in this analysis 51,6 per cent were drilled in igneous or metamorphic rocks with only 20,4 per cent of success. The percentage of success in the 12,9 per cent of the boreholes drilled in schist was even lower viz. 14,3. Of the 35,5 per cent of the boreholes drilled in the quartzitic sediments 54,7 per cent were successful. A histogram (Fig. 24) shows the results schematically. These dramatic differences in the water-yielding capacities of the different rock-types can be explained by the type and degree of weathering. The intrusion of the granite and probable later tectonic movements metamorphosed the rocks of the Swaziland System. The arenaceous sediments were altered to quartzitic rocks in which secondary structures were developed. The joints, fractures,and cleavage tend to be further opened by subsequent weathering, increasing the permeability. The originally shaly and calcareous rocks developed a schistose or granulitic structure, with decrease of permeability. Clay was formed by subsequent weathering. The clay is practically an aquiclude, and therefore the permeability was further reduced.

The so-called igneous rocks seem to be derived from intermediate to basic lavas and associated rocks. These rocks have low permeabilities, and the amphibolites to which they were altered, weathered to clayey products. In most of the boreholes drilled into these rocks, no intermediate zone is found between the highly-weathered clayey material and the solid rock. In electrical borehole logging we find a sharp contact between a weatered zone with a resistivity of 80 to 120 ohm m, and solid rock with resistivities of 1 000 to 8 000 ohm m. In the

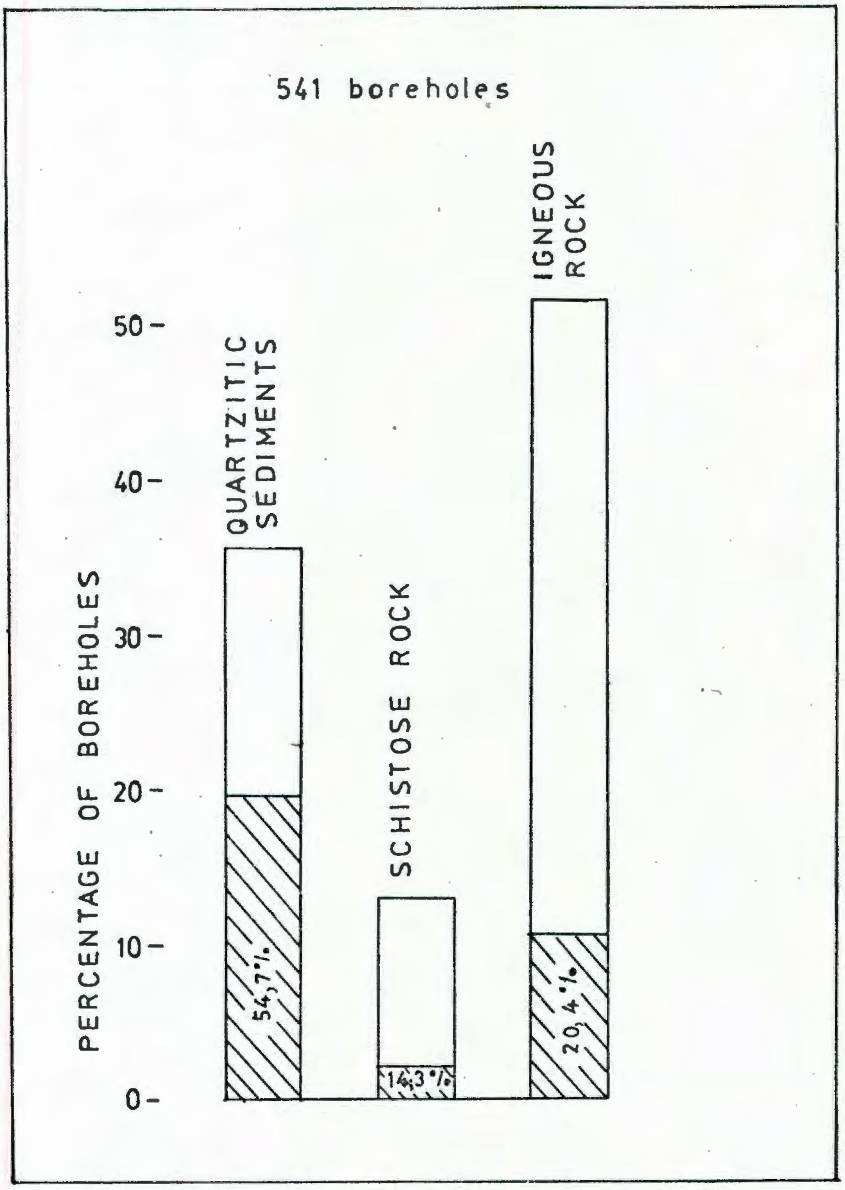


FIG. 24 - HISTOGRAM OF PERCENTAGES OF BOREHOLES IN DIFFERENT ROCK-TYPES, SWAZILAND SYSTEM, N.W. TRANSVAAL. (Successful boreholes shaded)

few boreholes in which an intermediate zone was present, good supplies of ground-water were usually found. Graphs are shown in Fig. 25.

6.1.7 THE EFFECT OF DYKES

The contacts of some syenitic dykes in the Swaziland System could be determined accurately by the magnetometer. Fifteen boreholes were drilled on or next to dykes in this system, with the following results:-

(i) Two boreholes drilled on the dykes. Both dry.

(ii) Seven boreholes were drilled on the contacts of dykes, sometimes cutting the dyke at, or just below, the ground-water rest level. Of these boreholes 57 per cent were successful.

(iii) Six boreholes were drilled between 15 and 91 m from the contact of a dyke. Of these 50 per cent were successful.

If the two boreholes which were drilled on dykes and struck solid syenite at a shallow depth is excluded, 53,8 per cent of the boreholes at or near the contacts of dykes were succesful in the Swaziland System. This is appreciably higher than the average for the area.

6.1.8 SUMMARY

(i) No optimum conditions could be found for the selection of successful boreholes in the Swaziland System in this area.

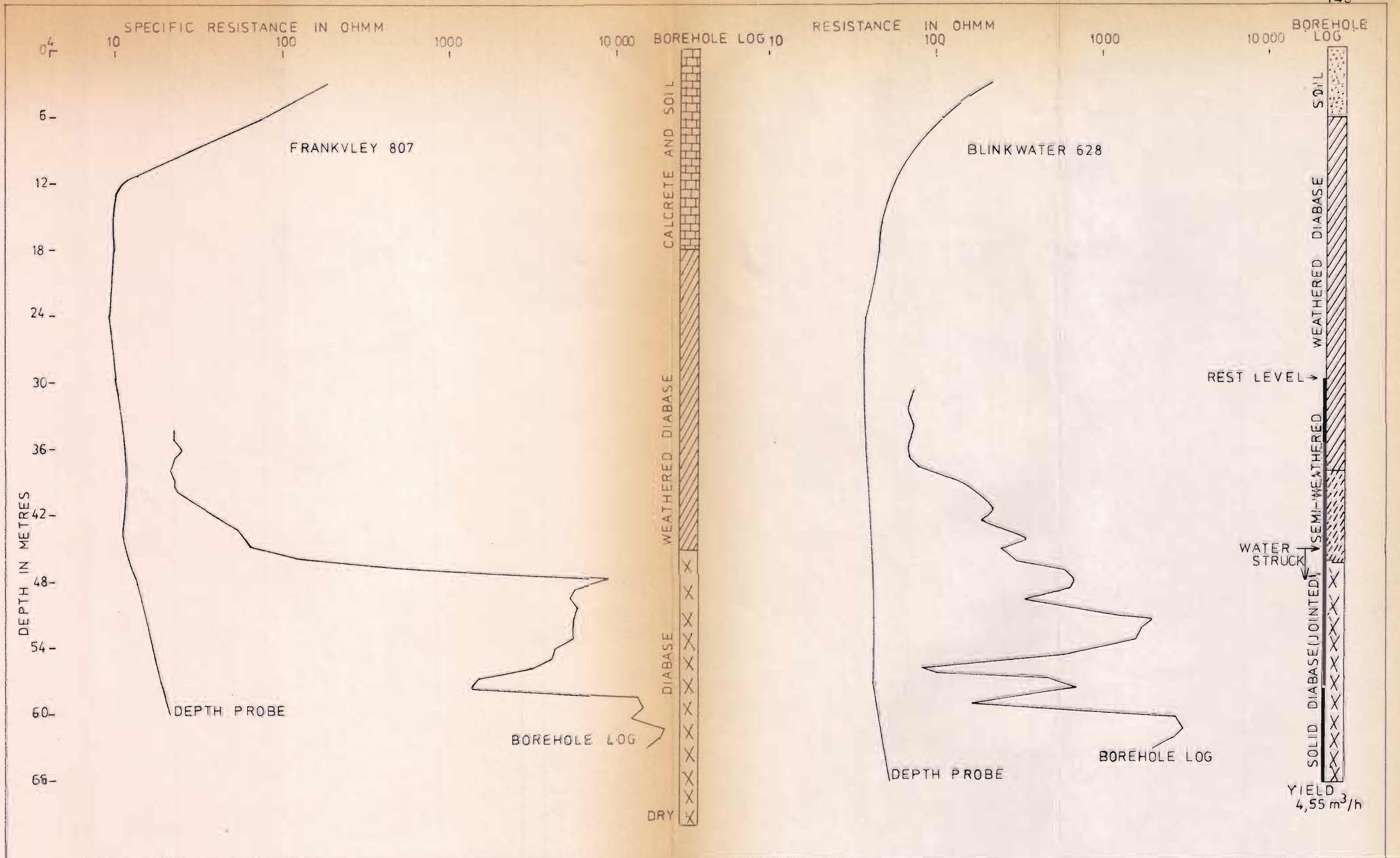


FIG.25 - DEPTH PROBES AND RESISTIVITY LOGS IN DRY AND SUCCESSFUL BOREHOLES, SWAZILAND SYSTEM, N.W. TRANSVAAL.

The percentage of successful boreholes can however, be increased by observing the following:

(a) By siting a borehole where the resistivity of the formation at the depth at which water is struck (usually 30 to 91 m) is between 40 and 110 ohm m. The possibility of finding an economic supply is even greater with resistivities between 50 and 80 ohm m.

(b) A depth of weathering (or depth to geophysical contact between low-resistivity and high-resistivity formations) of 48 to 76 m.

(c) A lush growth of large trees or a line of trees indicating deep weathering and/or secondary structures.

(d) A drainage line or laagte, or lacking this, a pan or depression where surface water can accumulate.

(e) A cover of calcrete at least 3 m thick, and a maximum of 1 m (0,3 m in the case of clayey soil) of soil covering it.

(f) If a dyke can be traced magnetically, the contact zone is more favourable for finding water than elsewhere, all other conditions being equal.

(g) Quartzitic sediments at the depth at which water is expected.

The presence of these formations can sometimes be deduced from resistivity depth probes, from statistics, or even from magnetic surveys e.g. Blinkwater 628. At present the information from boreholes cannot be correlated to yield a stratigraphic succession of the Swaziland System.

(ii) Water is usually found in the semi-weathered zone between the highly-weathered rock and solid rock, or in cracks and joints in the almost unweathered rock immediately below the weathered zone. The water-bearing zones are found between 10 m above and 10 m below the depth of weathering, with the optimum range of success between 3 m deeper or shallower than the depth of weathering. It is therefore not advisable to drill deeper than 10 m in solid rock, or to stop the borehole at a shallower depth, unless the supply is adequate at the shallower depth.

(iii) Practically all successful supplies are found at a depth shallower than 73 m. If no water has been struck when this depth is reached the borehole can be regarded as a failure.

(iv) The percentage of successful boreholes up to the time of the survey, was 32 per cent. In this area a yield of less than 1 m^3/h is regarded as uneconomic. Only 25 per cent of the boreholes yield 1 m^3/h or more. By careful selection of sites, within the restrictions enumerated above, this figure can be appreciably increased.

(v) In very few cases a permanent decline in the ground-water rest level could be observed, and then it was slight. On Laastepoort 840 a sharp decline was reversed after good rains, and by regulating the pumping program, the rest level was maintained thereafter. Therefore no serious overpumping was taking place in this area, and the recharge of ground-water probably balanced the withdrawal.

6.2 THE KHEIS SYSTEM

The Kheis System is divided into three series which differ appreciably in their lithological compostition and are therefore discussed separately as far as their hydrological properties are concerned.

6.2.1 THE MARYDALE SERIES

6.2.1.1 LITHOLOGY

The Marydale Series consists of metamorphic rocks derived from sediments and volcanics. The grade of metamorphism varies appreciably over the area, tending to increase towards the north-west. No adequate stratigraphic succession for the Marydale Series has been compiled to date. According to the available information from reports, and personal observation in the field, a tentative succession in the type area between Prieska, Sodium and Marydale is as follows, from top to bottom;

(a) Basic lava, mostly altered to amphibolite, sometimes with recognisable amygdales, and thin intercalated quartzite horizons.

(b) Acid lava, mostly altered to acid granulite, dark-coloured quartzite, gneissic granitised sediments, mica schist,biotite and hornblende granulite.

(c) Dolomitic limestone, marl, mostly altered to amphibolite, calc-silicate rocks, granulite.

(d) Basic lava often amygdaloidal, mostly altered to amphibolite.

(e) Ferruginous quartzite (banded ironstone), mica schist, phyllite, serpentine rock, gneissic granitised sediments, mostly derived from arenaceous rocks.

(f) Grit, graywacke and arkose in the south-east, probably wholly granitised towards the north-west.

The broad valleys between the ridges are mostly underlain by granitic sediments. Because of the differential weathering of the constituents of the granitic rocks, they crumble faster than the quartzitic sediments and even faster than the fine-grained basic lavas. They usually occupy the lowlands where only occasional outcrops are found.

The next important group is the amphibolites and lavas, which form low hills or occupy the foot-hills of ridges. Outcrops are more numerous than for the previous group, but contacts with other rock-types are seldom seen.

The dark-coloured quartzite, ferruginous quartzite, and horizons of white meta-quartzite usually form the crests of ridges. They crop out over smaller areas than the previous rocks.

The occurrence of ground-water can therefore be discussed with relation to the following groups:

(i) Granite and granitised sediments, and associated rocks.
(ii) Amphibolite and lava, including the granulites.
(iii) Quartzitic and arkosic sediments, and associated rocks.
(iv) Schistose and phyllitic rocks.

It must be mentioned here that the Namaqualand gneisses and

Grey Gneiss, although probably derived from the Kheis System, will be discussed separartely due to their wide distribution and generally homogeneous hydrological properties, depending more upon topography and climate than upon lithological differences.

6.2.1.2 GROUND-WATER IN THE GRANITE AND GRANITISED SEDIMENTS

Only the oldest granites in the eastern portion of the area, outcropping from the Omdraaisvlei area south-east of Prieska to the area north of Marydale where they disappear beneath the Soetlief Formation and the Matsap Beds, are discussed here. These granitic rocks have been determined by geochronological means to be 2 820 to 2 926 M.Y. old, and therefore older than the Geelbeksdam granite which is intrusive into the Soetlief Formation. They are definitely gneissic and inhomogeneous, with quartzitic intercalations and a horizon of granitised conglomerate with slightly elongated pebbles on the farm Jackalswater in the Prieska District.

It is seldom possible to distinguish these granitised sediments in hand specimens from the slightly younger Geelbeksdam granite, especially where granitisation is complete and remnants of quartzitic rocks do not occur. Both are often light-coloured and coarse-grained. The granitised sediments are, however, more gneissic with quartzitic intercalations, whereas the Geelbeksdam granite is homogeneous with pegmatitic varieties.

Adequate information was available from a total of 54 boreholes which were drilled in these granitised sediments. The average depth was 55 m and the range between 12 m and 123 m. Only 9,2 per cent were deeper than 91 m. Water was struck between 6 m and 83 m, with an average depth of 38 m. Only one supply was struck deeper than 76 m. Rest levels varied between 3 m and 76 m with an average depth of 21 m. Only one rest level was deeper than 57 m.

The average yield was 2,21 m^3/h, ranging between dry and 16,76 m^3/h. A total of 31 boreholes were successful, this being 57,4 per cent of the boreholes. This figure is a high percentage for the North-western Cape Province. It must be remembered that several of the unsuccessful boreholes were stopped above the ground-water rest level. The average yield of successful boreholes was 3,83 m^3/h, which is a very satisfactory figure for this area.

The depth of weathering averaged 20 m, ranging between 2 and 57 m. This is appreciably shallower than the depth at which water was struck, and even shallower than the rest level. Weathering was equal to or deeper than the depth at which water was struck in only nine of the boreholes (20,4 per cent). These were all successful boreholes.

This unexpected result can be explained by the fact that the secondary structures in the granitised sediments are permeable to a considerably greater depth than the depth of weathering. The arenaceous sediments were more susceptible to physical disintegration than chemical weathering. During granitisation and subsequent weathering the secondary structures must have remained open enough to allow circulation of ground-water to an appreciably greater depth than the depth of chemical weathering.

Very few electrical resistivity depth probes were done in this area for the selection of borehole sites. Good supplies were struck where the resistivity at the water level was between 45 and 260 ohm m. At boreholes with insufficient yield, resistivities varied between 140 and 600 ohm m.

Topography plays a very important role in the siting of successful boreholes. Because of the low rainfall, most of the boreholes described above are situated in laagtes or broad valleys. Approximately 33 per cent of the successful boreholes are situated near earthen dams, some of which were built before the boreholes were drilled, and others after, with the specific aim of increasing the yield of the borehole. Two strong boreholes (12,73 and 14,27 m^3/h) drilled for road construction on Irene and Springputs are situated in laagtes downstream of small earthen dams.

The surface covering on this granite is almost invariably calcrete, sometimes with thin soil or alluvium on it. On Stuurmansput very strong supplies were struck at shallow depths in a large laagte with very low gradient, where the calcrete is 10 to 15 m thick.

6.2.1.3 GROUND-WATER IN THE VOLCANICS

These rocks do not weather as easily as the granite, and usually form the slopes of ridges or low kopjes. It is therefore geologically and topographically not favourable for the finding of ground-water, and drillers try to avoid drilling in these formations. Only nineteen boreholes could be traced that were definitely drilled in the volcanics of the Marydale Series. Of these nine or 47,4 per cent were successful with an average yield of 2,24 m^3/h. The average depth of the boreholes was 38 m, ranging between 18 and 73 m. Water was struck at an average depth of 25 m with a range between 15 and 60 m, while the average rest level was 15 m, and the range 5 to 26 m. In 54 per cent of the boreholes the weathering was equal to or deeper than the depth at which water was struck, and in 91 per cent, deeper than the rest level. Ground-water was therefore usually found in the weathered volcanics, or in the semi-weathered rock immediately below the depth of weathering. The results were however too incomplete to draw a histogram.

6.2.1.4 GROUND-WATER IN THE SCHIST

The schist weathers easily and forms flat-lying areas with low relief. Because outcrops are scarce, it was not always possible to determine the stratigraphic position of a particular schist outcrop i.e. whether the schist should be grouped with the Marydale or Kaaien Series. All the schist which was not obviously quartz-schist or quartz-sericite schist, or could be definitely correlated with the Kaaien Series, was grouped with the Marydale Series.

Although it is easy to drill in schist, boreholes cave in easily at or below the ground-water rest-level, with the result that very few existing boreholes could be traced in which schist was found at the water level. Only fourteen could definitely be correlated with Marydale schist and of these only four (28,6 per cent) were successful. The average depth was 61 m, ranging between 27 and 109 m. The average depth is appreciably greater than in the granite and volcanics, due to the ease of drilling. Water was struck at an average depth of 55 m, and the average rest level was 45 m, both being appreciably deeper than in the formations described above. This is rather surprising, and proves that the schist is slightly permeable, probably along the foliation, to a greater depth than the granite and lava. The average yield of the boreholes was only 0,45 m^3/h.

6.2.1.5 GROUND-WATER IN THE QUARTZITIC SEDIMENTS

On Welgevonden, Modderfontein, Waterkop and other farms to the south and west of Prieska, the ferruginous quartzite (banded ironstone) of the Marydale Series forms ridges and kopjes standing out sharply above the plain. South of Marydale dark-coloured quartzite on Happy Valley, Kareeboomput and Stuurmansput is intricately folded, forming ridges and necks between valleys in which the granitised sediments of the Marydale Series are found. Further north near the Orange River the same type of quartzite was seen as low ridges between sand-dunes on Matjiesrivier and Trooilapspan. According to Joubert (1971) some of the meta-quartzites of Bushmanland and Namaqualand probably belong to the Marydale Series. They are very important aquifers in these areas, because of their high permeability, generally along secondary structures; and they yield some of the ground-water with the best quality in the area.

The town of Springbok depended on this aquifer for the greater portion of its domestic water-supply before water was supplied by the O'okiep Copper Co. from the sand-bed of the Buffels River.

Due to the close similarity between the hydrological properties of these quartzites and that of the Kaaien Series they are grouped together for hydrological interpretation.

6.2.2 THE KAAIEN SERIES

6.2.2.1 LITHOLOGY

In this area the Kaaien Series probably consists of the following:

(i) Rocks retaining obvious sedimentary characteristics and consisting of quartzite, meta-quartzite, ferruginous quartzite, meta-conglomerate, quartz-schist, quartz-sericite schist, silimanite schist, staurolite schist, quartz-mica schist, chlorite schist, and probably some biotite-muscovite schist.

(ii) Metamorphosed and granitised rocks probably derived from more argillaceous and arkosic members of the Kaaien Series. They include pink gneiss, para-gneiss, various types of granulite, and some of the rock-types called reconstituted sediments of the Kaaien Series by Von Backström (1964). Most of the amphobolite, marble, calc-silicate rocks, some biotite schist and biotite-hornblende gneiss (grouped under the para-gneiss by Von Backström, 1964) are grouped with the Marydale Series, in which similar rock-types are found. This view is shared by Du Toit (1968) who mapped the areas to the east and north of Sheet 207 (Keimoes). He also points to the similarity of the bands of quartzite intercalated in the lava of the Marydale Series near the top of this succession, with the quartzite of the Kaaien Series.

Due to the intricate folding and re-folding of the pre-Cambrian rocks in this area (Joubert, 1971), and the high and variable degree of metamorphism, it is often impossible to unravel the stratigraphic sequence.

Due to the fact that only arenaceous sediments and reconstituted sediments are included under the Kaaien Series, all the rock-types of the Kaaien Series will be treated as two hydrological units viz. one unit of quartzitic sediments, and another unit of granitic and gneissic rocks.

6.2.2.2 DISTRIBUTION

The distribution of outcrops of Kaaien sediments which are not granitised, is much wider than the sediments of the Marydale Series. This is partly due to the greater resistance to weathering of the quartzitic sediments, thus giving more prominence to their distribution. Due to the greater competence of these rocks, secondary structures are numerous as a result of deformation and metamorphism, and they are therefore relatively good aquifers. Hydrologically the Kaaien Series can be divided as follows:

(i) Quartzite including meta-quartzite, metamorphosed conglomerate, and quartz-sericite rocks which do not have a schistose structure.

(ii) Schist and schistose rocks are so subordinate, usually forming narrow horizons in the quartzitic rocks, that they can be disregarded as a hydrological unit.

(iii) Acid granulite and other granulitic rocks, including the kinzigites. Again, these rocks are so subordinate, except for the Aasvogelkop granulite, that it is not possible to discuss them as a separate hydrological unit, due to the small number of boreholes drilled in them.

The Aasvogelkop granulite occurs over large areas in the Kenhardt District, mostly to the north and east of the town. It is possible that some of the granulite now correlated with the Aasvogelkop granulite group, belongs to the Marydale Series, but this can only be determined after much more extensive and detailed mapping.

The contact between this granulite and the pink gneiss is often a gradational one. Von Backström (1964 and 1967) found it difficult to trace the contact outside the type area; and even in the type area found that the granulite graded into pink gneiss (Von Backström, 1964 p. 35). The origins of these two rock-types are identical, and the distinction between them rests mainly on differences in colour, and slight variations in chemical composition, resistance to weathering, and appearance. The Aasvogelkop granulite is therefore grouped with the pink gneiss and other gneiss as a hydrological unit, and discussed in the following section.

(iv) Gneiss, including the pink gneiss and para-gneiss.

6.2.2.3 QUARTZITIC ROCKS

Due to the highly-developed secondary structures, the Kaaien sediments are regarded as some of the best aquifers in the area. Percolation can proceed rapidly along the joints, cracks, fissures, shear zones and bedding-planes. Outcrops are numerous, and some of the main ridges and mountain chains are formed by, or topped by Kaaien quartzite. North of the Orange River ridges of Kaaien quartzite form long narrow north-south striking mountains rising from the sand-covered flats. Under a thin cover of sand (3 to 10 m) it is still an effective aquifer with direct infiltration of rain-water, but where the cover of sand is thicker no direct infiltration to the quartzite occurs (Martin, 1961), and the possibility of finding adequate supplies of water depends on rainfall in outcrop or sub-outcrop areas and the rate of seepage along structures in the quartzite itself. It is usually well-bedded, and the dip and strike can be determined from outcrops.

6.2.2.3.1 SELECTION OF BOREHOLE SITES

Much of the basic work in the selection of borehole sites can be done geologically by observing dip and strike of the quartzite, the topography, evidence of secondary structure, and degree of weathering. Under a cover of soil, sand or alluvium it is sometimes necessary to use the resistivity apparatus to find the best site for drilling.

As in the formations described previously, it is again necessary due to the aridity of the area, to select sites where infiltration can take place after the accumulation of surface water. Laagtes, pans, earthen dams and gatdamme increase the possibility of striking an economical supply of ground-water. Prospects for finding good supplies are also better where underground barriers occur, so that the water accumulates at an economical depth, or is forced up to a depth from which it can be extracted at a reasonable cost.

6.2.2.3.2 STATISTICS

Because of its good hydrological properties, a large number of boreholes have been drilled in this formation. The borehole records of a total of 640 boreholes have been analysed. This number included some boreholes in quartzite of the Marydale Series, which is hydrologically identical. The results of the analyses are given below:

(i) Yield. Fig. 26(a) and Table III. The cumulative graph shows that 54 per cent of the boreholes were failures, while 14,7 per cent yielded more than 4,55 m^3/h; which is a very high percentage of boreholes with strong yields in this area.

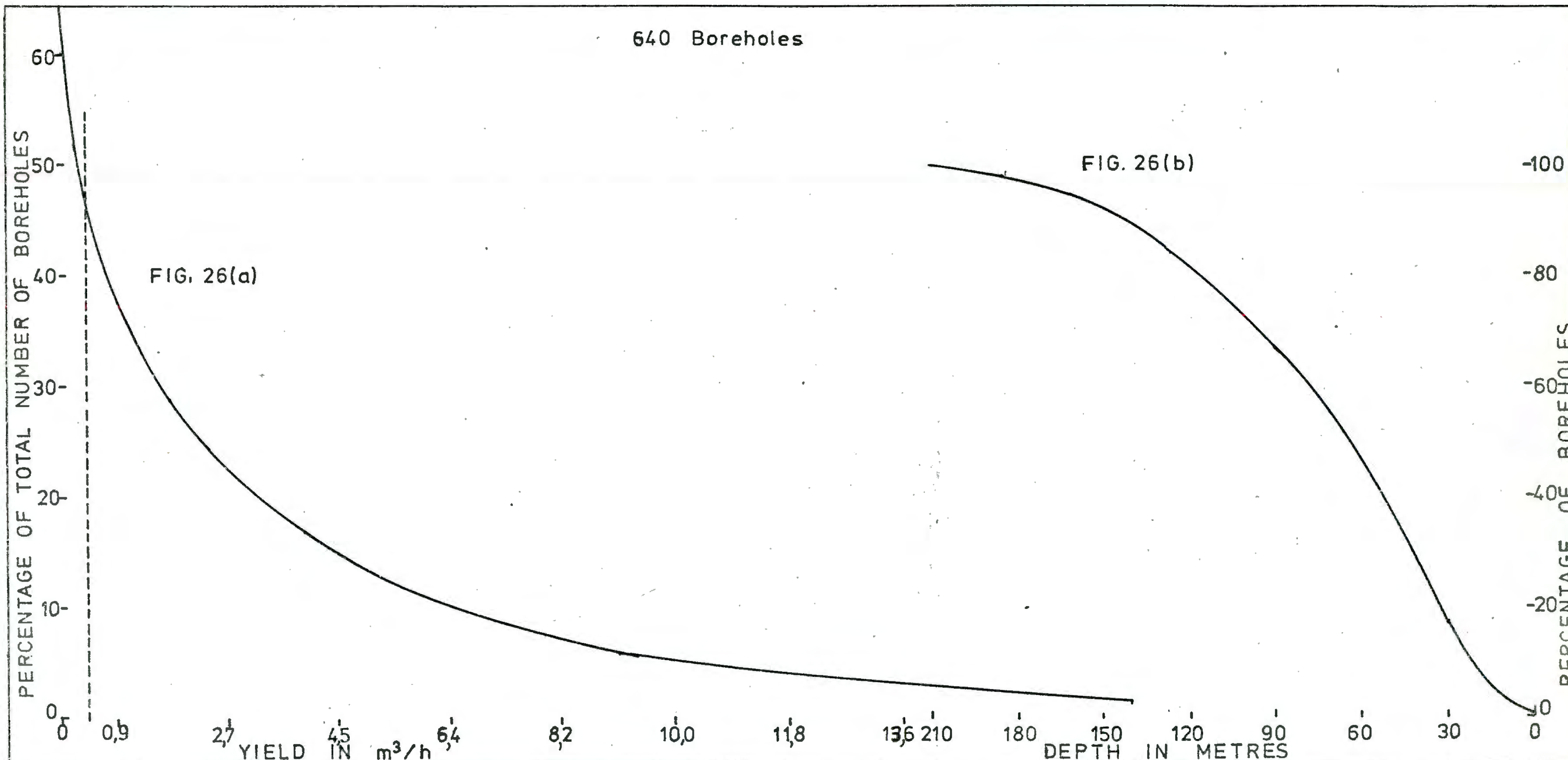


FIG. 26 - (a) CUMULATIVE GRAPH OF YIELD RELATIVE TO THE PERCENTAGE OF TOTAL NUMBER OF BOREHOLES. (b) CUMULATIVE GRAPH OF DEPTH RELATIVE TO THE PERCENTAGE OF TOTAL NUMBER OF BOREHOLES.
QUARTZITIC SEDIMENTS OF THE KAAIEN AND MARYDALE SERIES, N.W.CAPE PROVINCE.

TABLE III. YIELD OF BOREHOLES IN QUARTZITIC SEDIMENTS OF THE KHEIS SYSTEM IN THE NORTH-WESTERN CAPE PROVINCE RELATIVE TO (a) THE DEPTHS OF BOREHOLES, AND (b) THE PERCENTAGE OF THE TOTAL NUMBER OF BOREHOLES.

Depth in m	Yield in m^3/h											Total number of boreholes	Percentage	Cumulative Percentage
	unsuccessful			successful										
	0	0 -0,27	0,27 -0,45	0,45 -0,91	0,91 -1,36	1,36 -1,82	1,82 -2,73	2,73 -4,55	4,55 -9,09	9,09 -13,64	13,64 -23,04			
30	49	5	3	7	3	6	10	7	11	3	4	108	16,9	
30-45	38	5	1	10	5	6	3	10	16	6	6	105	16,4	33,3
45-75	24	12	4	6	3	5	7	13	10	2	2	88	13,7	47,0
60-75	27	12	3	5	5	6	1	6	7	1	1	74	11,6	58,6
75-90	17	13	4	5	3	5	1	6	0	0	1	55	8,6	67,2
90-120	29	17	6	9	4	5	7	5	5	3	2	92	14,4	81,6
120-150	30	19	1	4	2	1	2	3	6	2	2	72	11,2	92,8
150-180	7	5	2	4	2	1	2	0	4	0	0	27	4,2	97,0
180-210	6	4	3	4	2	0	0	0	0	0	0	19	3,0	100,0
Total	227	92	27	54	29	34	33	50	59 59	17 17	18 18	640 640	100,0 100,0	
Percentage	35,5	14,4	4,2	8,4	4,5	5,3	5,2	7,8	9,2	2,7	2,8	100,0		
Cumulative Percentage		49,9	54,1	62,5	67,0	72,3	77,5	85,3	94,5	97,2	100,0			

In Table III the results of the analysis of the 640 boreholes drilled in the quartzitic sediments of the Kheis System with regard to depth and yield are shown. Shallow boreholes of less than 30 m in depth, had the highest percentage of dry boreholes. The number of boreholes drilled deeper than 150 m is small, and the average yield decreased sharply tc less than 0,4 m^3/h for boreholes deeper than 180 m. The percentage of successful boreholes decreased to 34,7 per cent for boreholes drilled deeper than 120 m.

(ii) Depth. Fig. 26(b). Boreholes were drilled deeper than in most of the other formations in this area, especially in its western portion. Although 67 per cent were shallower than 90 m, 18,4 per cent were deeper than 120 m, and 3 per cent deeper than 180 m.

(iii) Depth at which water was struck. Fig. 27. In 65,8 per cent of the total number of boreholes water was struck shallower than 60 m, in 78,4 per cent shallower than 90 m, and in 6,6 per cent deeper than 120 m. In successful boreholes the percentages for the same depth intervals were 69,5; 82,5; and 6,6 respectively. There is thus very little difference between successful and unsuccessful boreholes.

(iv) Rest levels are shown in Fig. 28 for 399 boreholes and for 293 successful boreholes. In the successful boreholes it

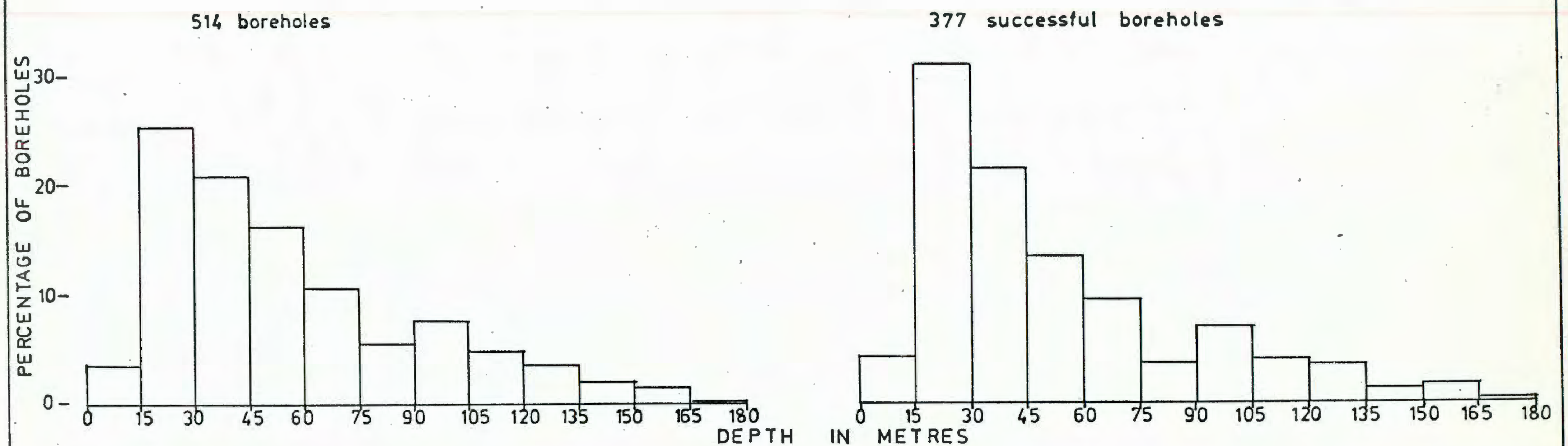


FIG. 27 - HISTOGRAMS OF THE DEPTH AT WHICH WATER WAS STRUCK IN THE QUARTZITIC SEDIMENTS OF THE MARYDALE AND KAAIEN SERIES, N.W.CAPE PROVINCE.

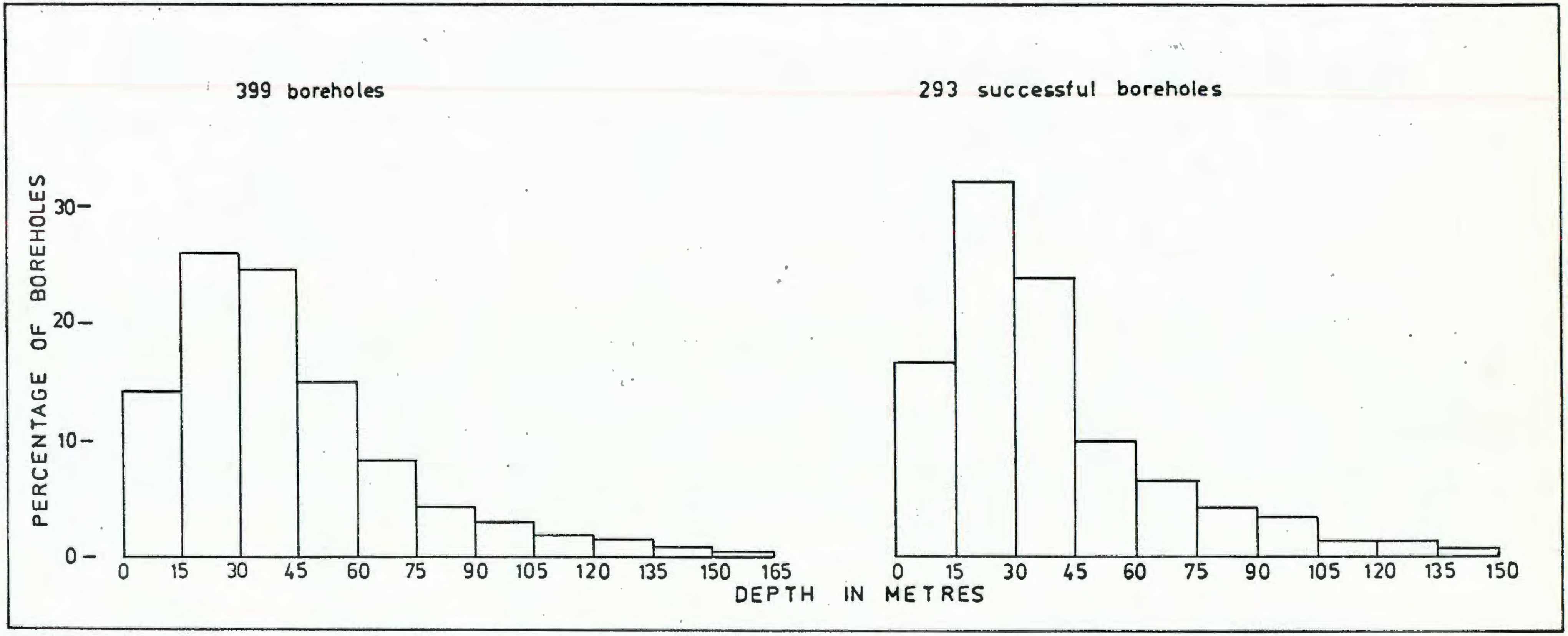


FIG. 28 - HISTOGRAMS OF REST LEVELS IN BOREHOLES IN THE QUARTZITIC SEDIMENTS OF THE KHEIS SYSTEM, N.W. CAPE PROVINCE.

was slightly shallower than in unsuccessful ones. Nearly 50 per cent of successful boreholes have rest levels shallower than 30 m, and 73 per cent shallower than 46 m.

(v) Depth of weathering relative to depth at which water was struck. (Fig. 29). Due to the fact that such a large percentage of borehole records are incomplete, the depth of weathering in the quartzite could only be determined in 307 boreholes. In 33 per cent of the boreholes water was struck at a shallower depth than the depth of weathering, and in 67 per cent deeper. This can readily be explained by the competency of the quartzite, and therefore the relative abundance of permeable secondary structures. The low rainfall and very limited infiltration prevent the occurrence of a universal water table. The depths at which water was struck ranged from 42 m shallower to 140 m deeper than the depth of weathering. Sixty-one per cent of the boreholes struck water between 18 m shallower and 24 m deeper than the depth of weathering.

(vi) The depth at which water was struck relative to the rest level. Fig. 30 shows this relationship as a cumulative graph, both for all the boreholes (a total of 515) which yielded water, and for the successful boreholes (376). In 60 per cent of the boreholes water was struck within 12 m of the rest level, demonstrating the good permeability and numerous secondary structures. Nevertheless, in 5,8 per cent of the boreholes water was struck more than 48 m below rest

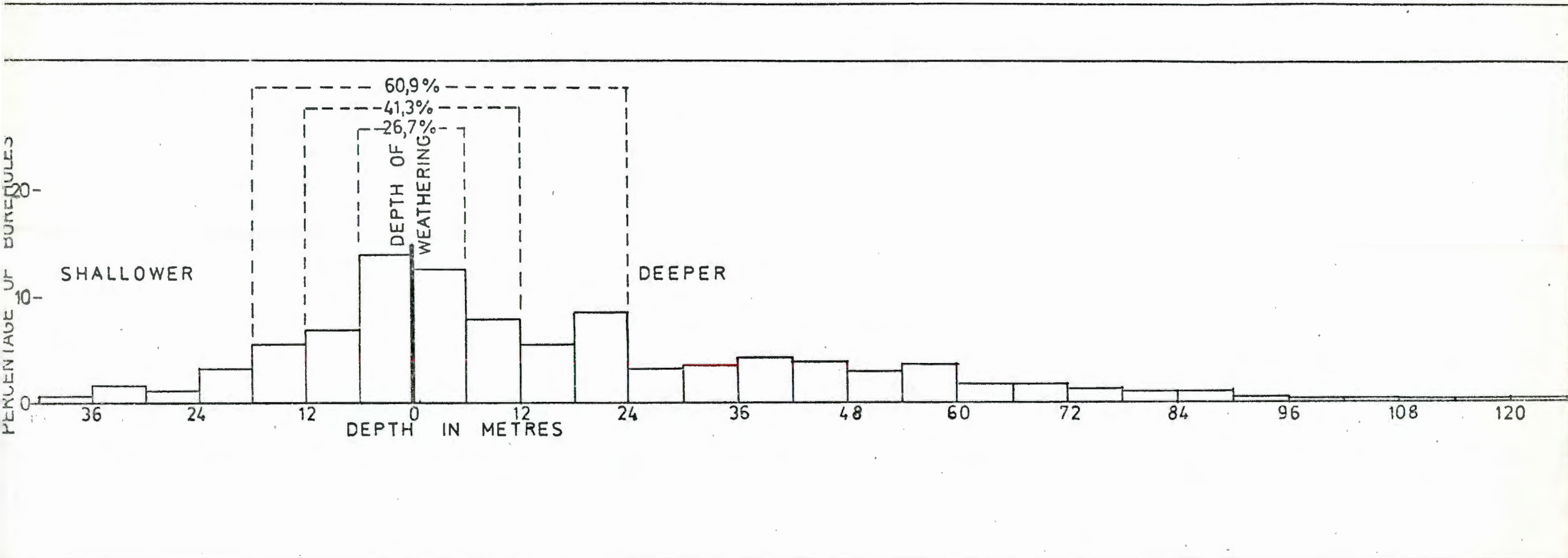


FIG. 29 - HISTOGRAM OF DEPTH OF WEATHERING RELATIVE TO THE DEPTH AT WHICH WATER WAS STRUCK, QUARTZITIC SEDIMENTS OF THE KHEIS SYSTEM, N.W. CAPE PROVINCE.

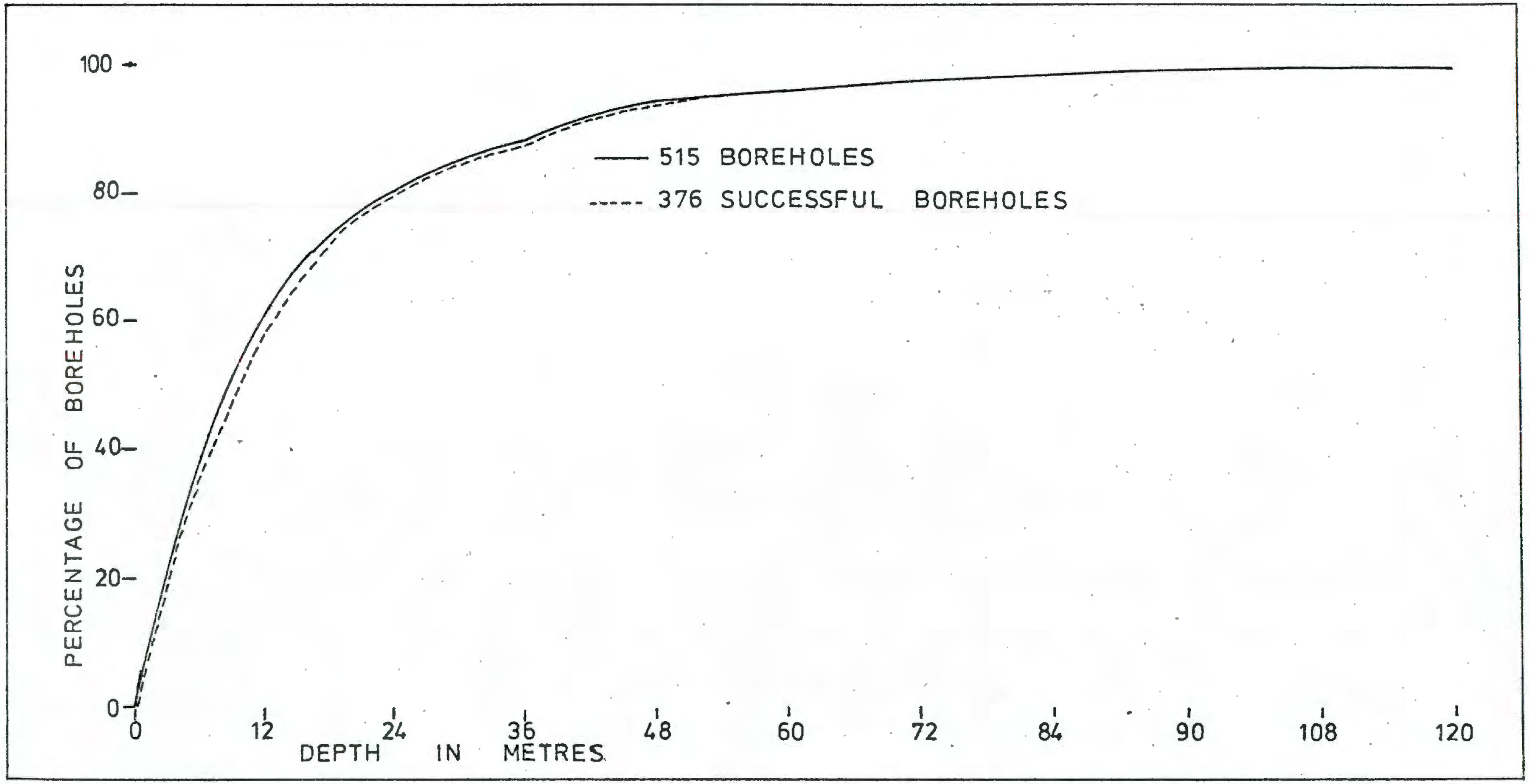


FIG.30 - CUMULATIVE GRAPH OF DEPTH BELOW REST LEVEL AT WHICH WATER WAS STRUCK IN QUARTZITIC SEDIMENTS OF THE KHEIS SYSTEM N.W.CAPE PROVINCE.

level, the maximum registered being 134 m. These results can probably be explained by the great depth to which these boreholes had to be drilled before a permeable secondary structure was encountered. The graphs for successful borholes and the total number of boreholes are practically identical.

6.2.2.3.3 ANALYSES OF GEOPHYSICAL SURVEYS

(i) The apparent resistivity was measured at 106 boreholes drilled in the quartzitic sediments of the Kheis System in the North-western Cape Province. From the histograms of the apparent resistivity between the ground-water rest level and the depth at which water was struck, as a function of yield (Fig. 78(a)), can be seen that a very high average yield of 7,1 m^3/h was found in the 15 boreholes in which the resistivity was less than 40 ohm m. Between 40 and 400 ohm m the average yield was 2,5 m^3/h, and for higher resistivities 0,3 m^3/h.

All the boreholes in which the apparent resistivity was less than 40 ohm m, were successful (Fig. 78(b)). Between 40 and 400 ohm m 72 per cent were successful, and for higher resistivities only 20 per cent of a total of five boreholes. It is obvious that the best results were obtained where the quartzitic sediments were weathered, sheared or jointed, so that a low resistivity was measured.

(ii) Electrical borehole logging was done in 31 boreholes in this formation, of which 90 per cent were successful.

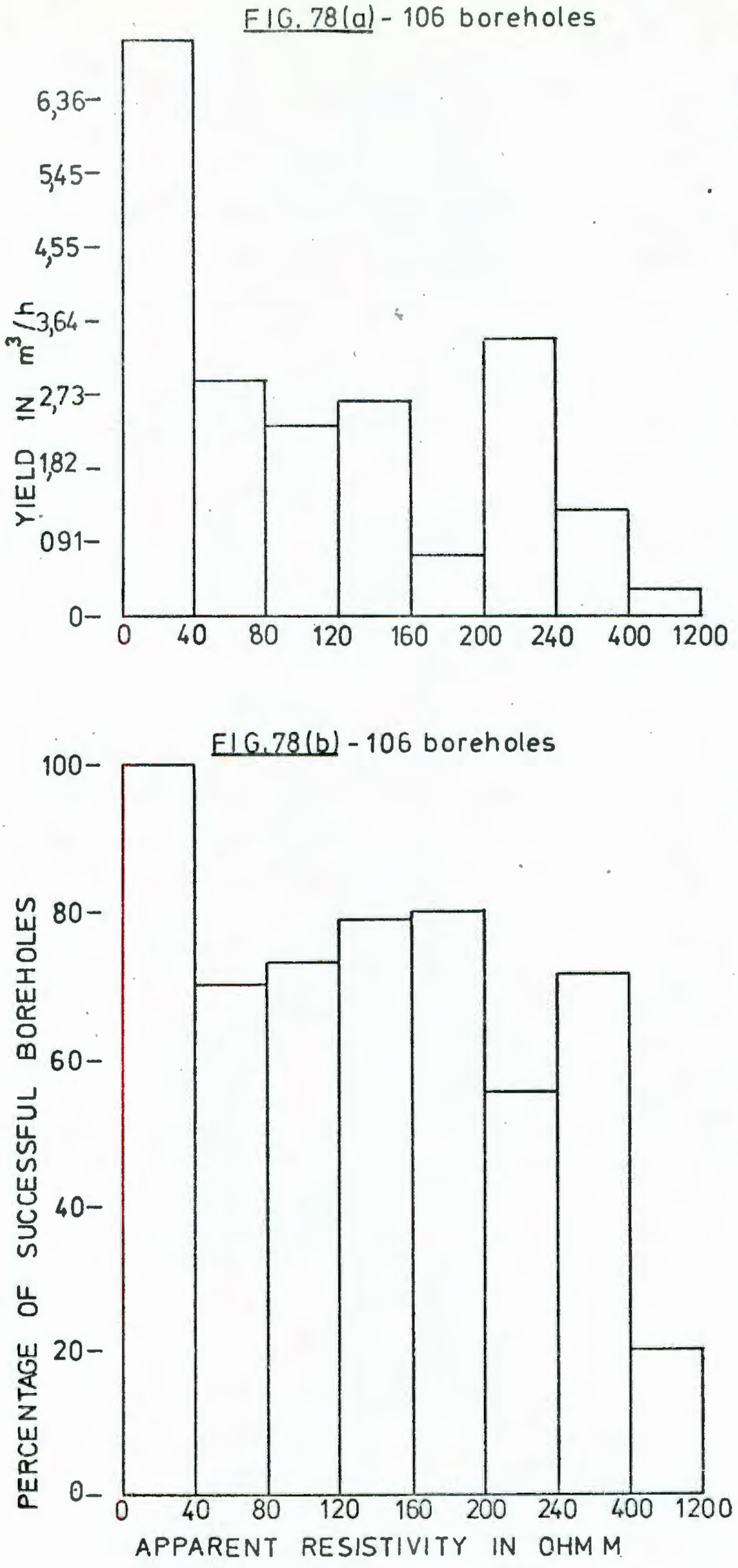


FIG.78 - HISTOGRAMS OF THE APPARENT RESISTIVITY AT THE REST LEVEL AS A FUNCTION OF THE (a) YIELD OF BOREHOLES; (b) PERCENTAGE OF SUCCESSFUL BOREHOLES; QUARTZITIC SEDIMENTS, KHEIS SYSTEM, N.W.CAPE PROVINCE.

Only three boreholes were found in which the yield was less than 0,45 m^3/h, the depth of water was sufficient for measurements, and the borehole was not destroyed after completion of drilling. No conclusions can, therefore, be drawn from the histogram of the specific resistance below the ground-water rest level as a function of the percentage of successful boreholes (Fig. 82(b)). The histogram of the specific resistance as a function of yield (Fig. 82 (a)), shows that the highest average yield is reached in the 10 boreholes with specific resistance of less than 20 ohm m. Average yields of over 3 m^3/h were, however, still found with specific resistances of 400 to 800 ohm m. In these boreholes the ground-water probably occurred in narrow cracks or joints in unweathered quartzite.

6.2.2.4 PINK GNEISS, PARA-GNEISS, AND AASVOGELKOP GRANULITE

There is no sharp distinction between these three rock-types. The Aasvogelkop granulite grades into the pink gneiss, and it is sometimes difficult to decide whether a certain outcrop must be grouped with the pink gneiss or the para-gneiss. Du Toit (1968) found a definite similarity between the pink gneiss and para-gneiss, even in colour in certain areas. These rocks are therefore treated as a hydrological unit.

The granulite and gneiss show definite banding or foliation, and remnants of the original bedding. Secondary structures such as fissures, joints, shear-zones and crush zones, are often

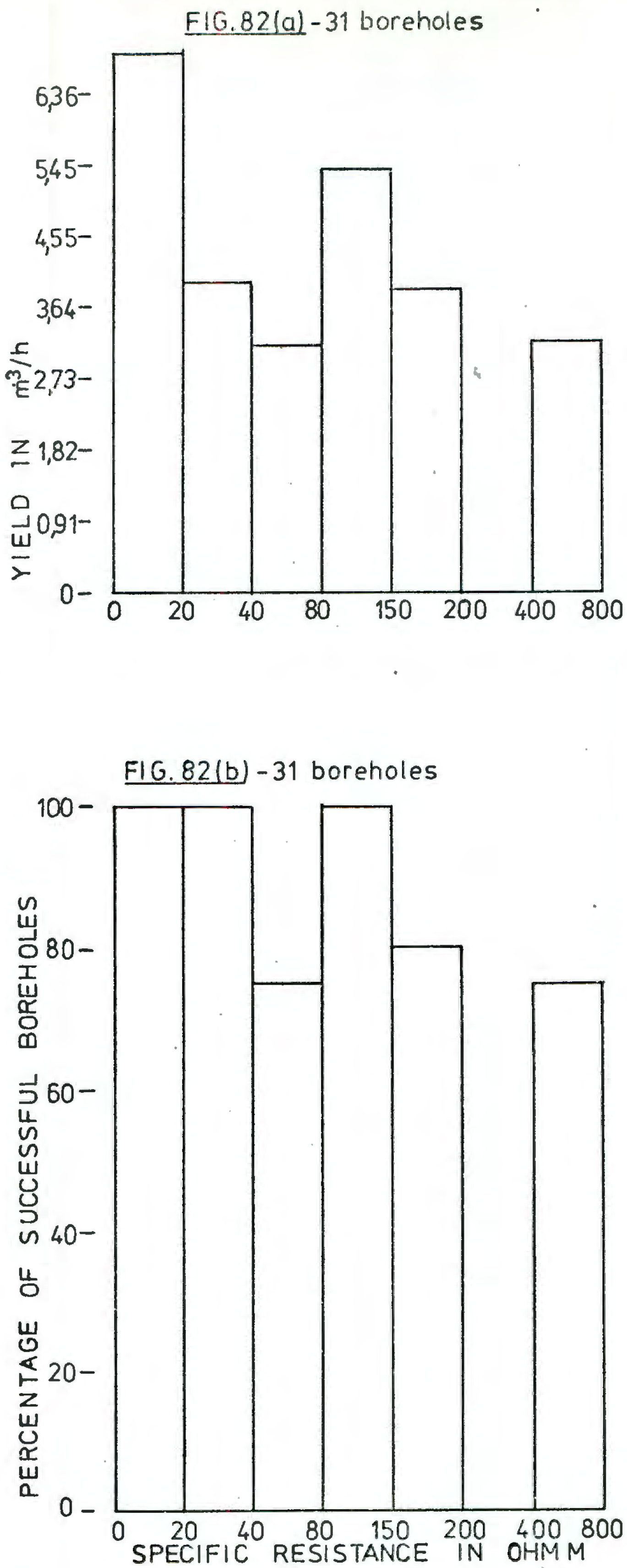


FIG.82 - HISTOGRAMS OF SPECIFIC RESISTANCE AT THE REST LEVEL (according to borehole logging) AS A FUNCTION OF THE (a) YIELD OF BOREHOLES; (b) PERCENTAGE OF SUCCESSFUL BOREHOLES; QUARTZITIC SEDIMENTS, KHEIS SYSTEM, N.W. CAPE PROVINCE.

visible at the surface, and are open down to the ground-water rest level, so that percolation is relatively fast. Chemical weathering is not very advanced, due to the arid climate. Consequently these rocks are good aquifers, especially where the water level is shallow. The granulite often forms ridges or high ground, as Aasvogelkop and the Piet Rooi's Mountains. More generally these rocks weather faster than the quartzitic sediments, and are found in the valleys and along the slopes of hills. Large areas are covered by calcrete and wind-blown sand. In these cases resistivity depth probes are used to determine the relative depths of weathering. The difference in weathering from place to place is more important than the actual order of resistivity. This statement is especially true of this area in which ground-water storage occurs in isolated basins, and the quartzitic type of rock has high surface resistance and deep rest levels.

6.2.2.4.1 STATISTICS

The results of 216 boreholes drilled in the gneissic and granulitic rocks were traced, and the analyses are shown on histograms and cumulative percentage graphs in Figs. 31 to 35. The percentage of successful boreholes was practically the same as for the quartzitic sediments viz. 45 per cent for the one and 46 per cent for the other. (Fig. 31) As can be expected in granitised sediments, the yield was slightly lower than for the quartzitic sediments. Nearly 24 per cent of the

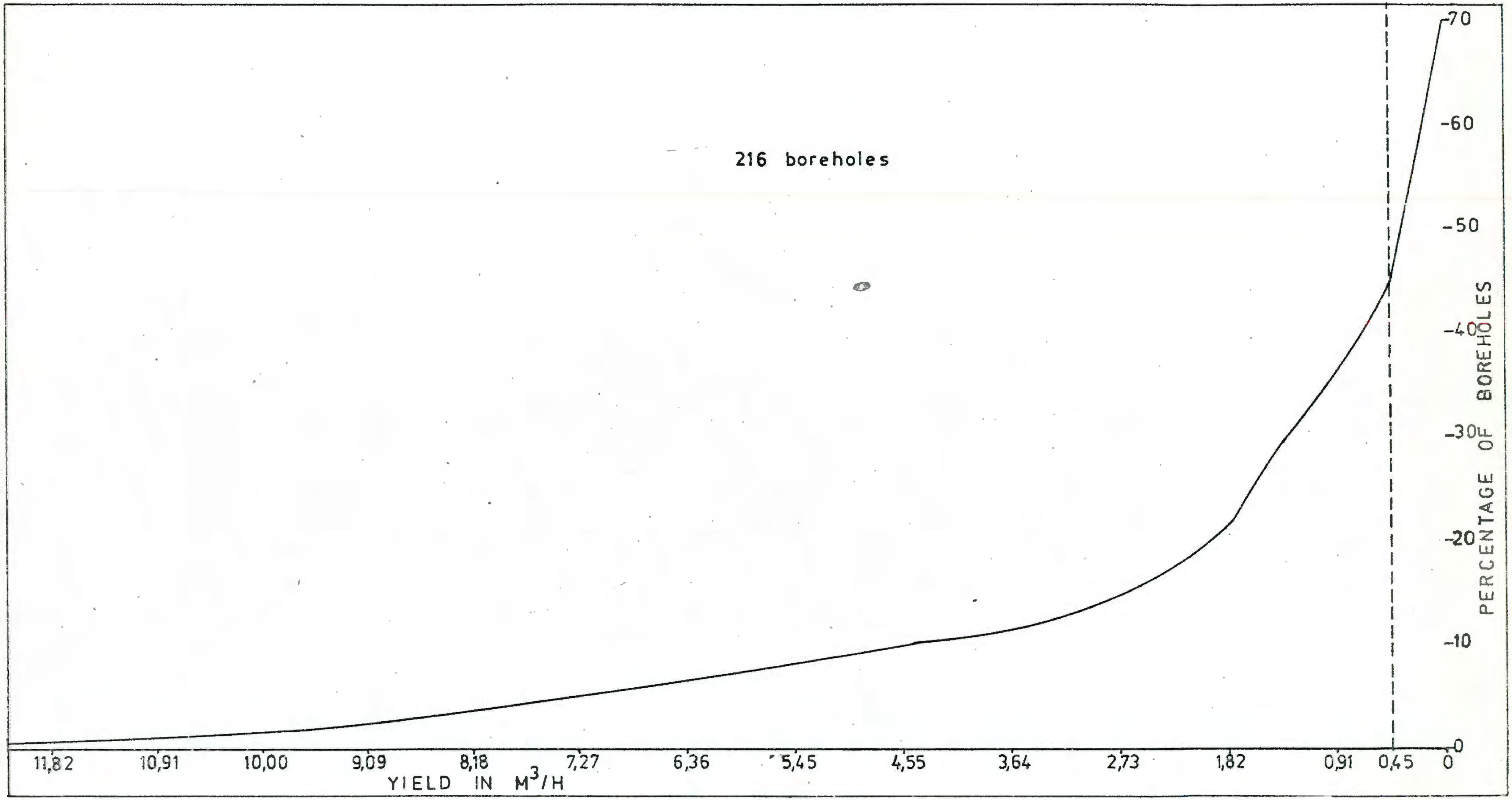


FIG.31 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF TOTAL NUMBER OF BOREHOLES, GRANITISED SEDIMENTS OF THE KAAIEN SERIES, N.W. CAPE PROVINCE.

successful boreholes yielded less than 1,82 m^3/h, and only 9,7 per cent more than 4,54 m^3/h. In the quartzitic sediments the respective percentages were 18,2 and 14,7. Boreholes were not very deep, the maximum depth recorded being 153 m; 86 per cent of the boreholes being shallower than 91 m (Fig. 32). In 80,7 per cent of the boreholes water was struck shallower than 61 m and in 92,7 per cent shallower than 76 m (Fig. 33(a)). In the case of successful boreholes the percentages were 87,4 and 96,9 respectively. Rest levels are relatively shallow, being less than 45,5 m in 81,7 per cent of the boreholes, and less than 61 m in 94,4 per cent (Fig. 33(b)). For successful boreholes the percentages were 88,6 and 97,5 respectively. The depth at which water was struck and the average rest levels were, therefore, appreciably shallower than in the quartzitic sediments. This may be explained by the fact that the depth to which secondary structures were open, was generally less in the granitised sediments than in the quartzitic sediments. Permeable structures therefore did not extend as deep as in the latter, and the water accumulated at shallower depths.

In 63 per cent of the boreholes water was struck within 12 m of the rest level (Fig. 34), and in 82 per cent within 24 m. These percentages are even higher than for the quartzitic sediments, probably because the average depth at which water was struck, was less than in the latter.

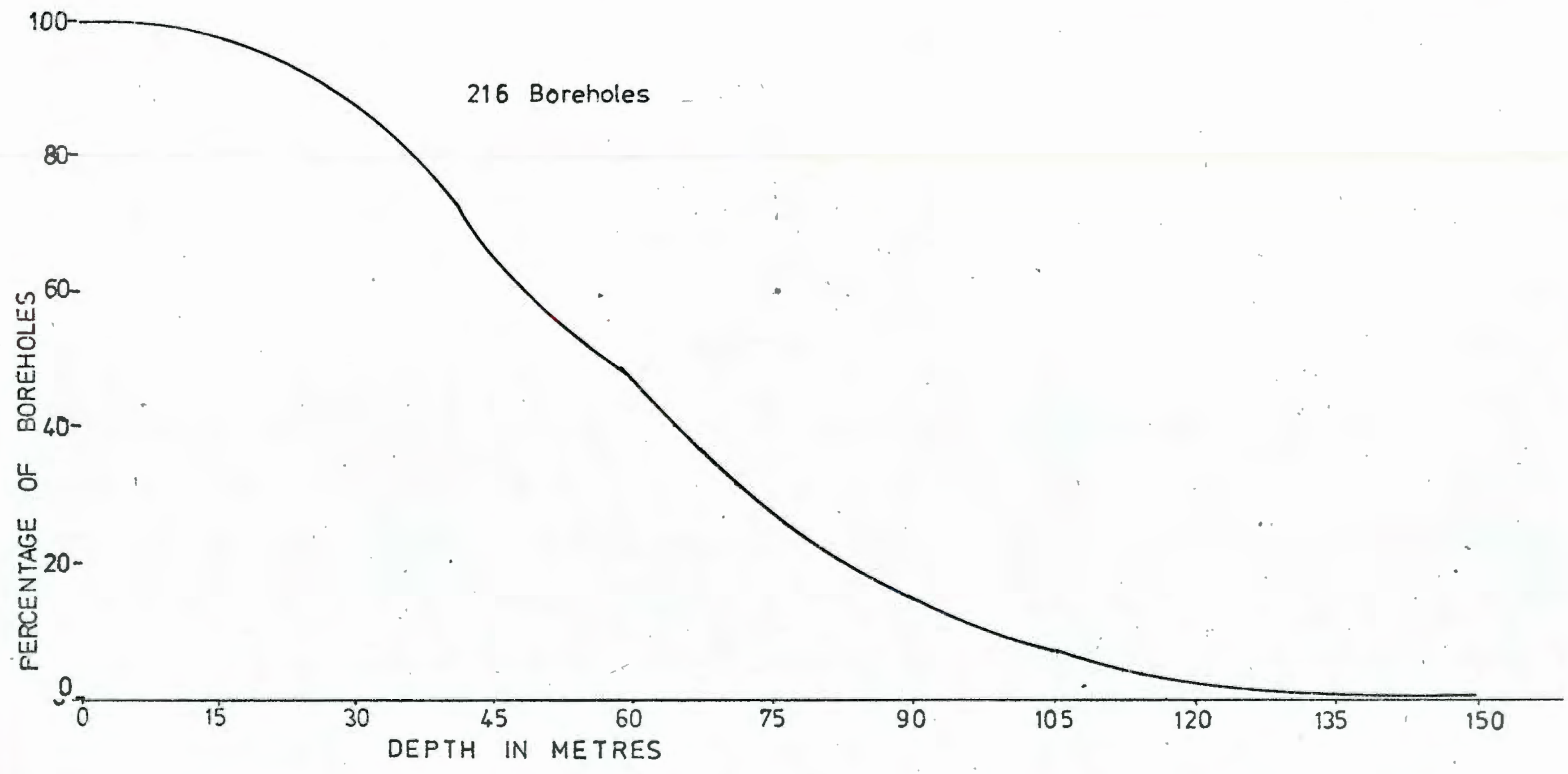


FIG. 32 - CUMULATIVE GRAPH OF THE DEPTHS OF BOREHOLES AS A FUNCTION OF THE PERCENTAGE OF THE TOTAL NUMBER OF BOREHOLES, GRANITISED SEDIMENTS OF THE KAAIEN SERIES, N.W.CAPE PROVINCE.

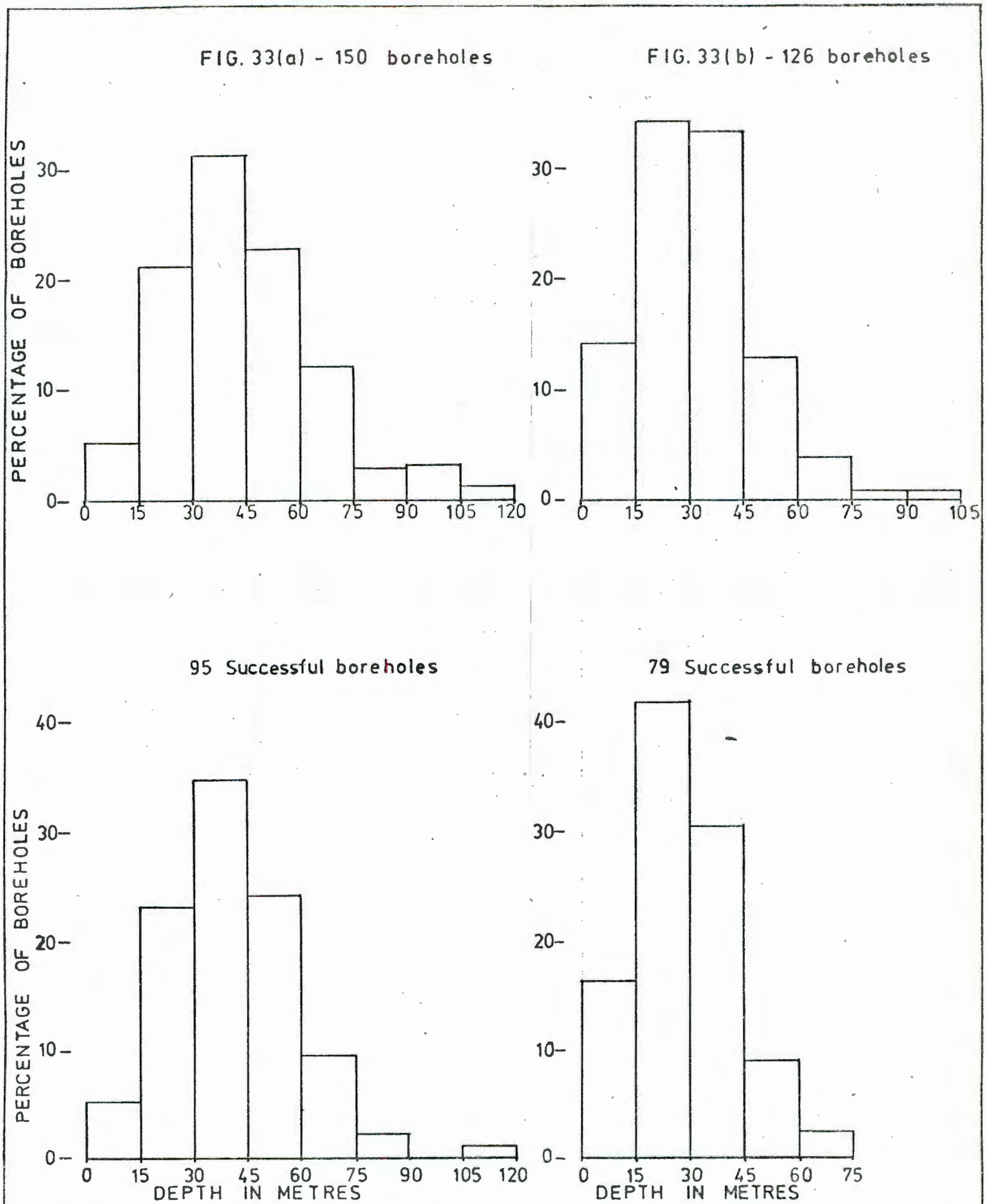


FIG.33 - HISTOGRAMS OF (a) DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE NUMBER OF BOREHOLES; (b) REST LEVELS AS A PERCENTAGE OF THE NUMBER OF BOREHOLES; GRANITISED SEDIMENTS OF THE KHEIS SYSTEM; N.W. CAPE PROVINCE.

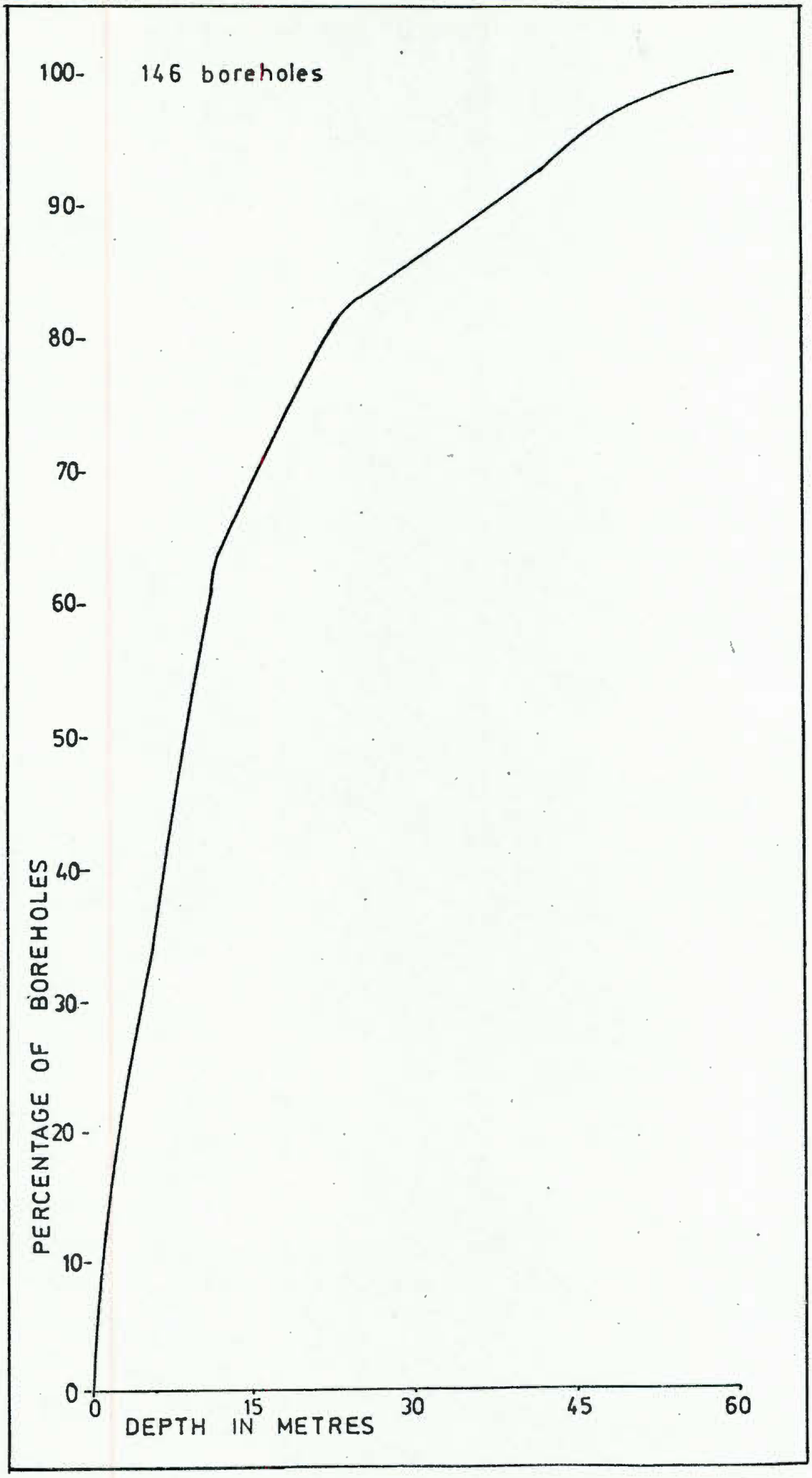


FIG.34 - CUMULATIVE GRAPH OF THE DEPTH BELOW REST LEVEL AT WHICH WATER WAS STRUCK, GRANITISED SEDIMENTS OF THE KHEIS SYSTEM, N.W. CAPE PROVINCE.

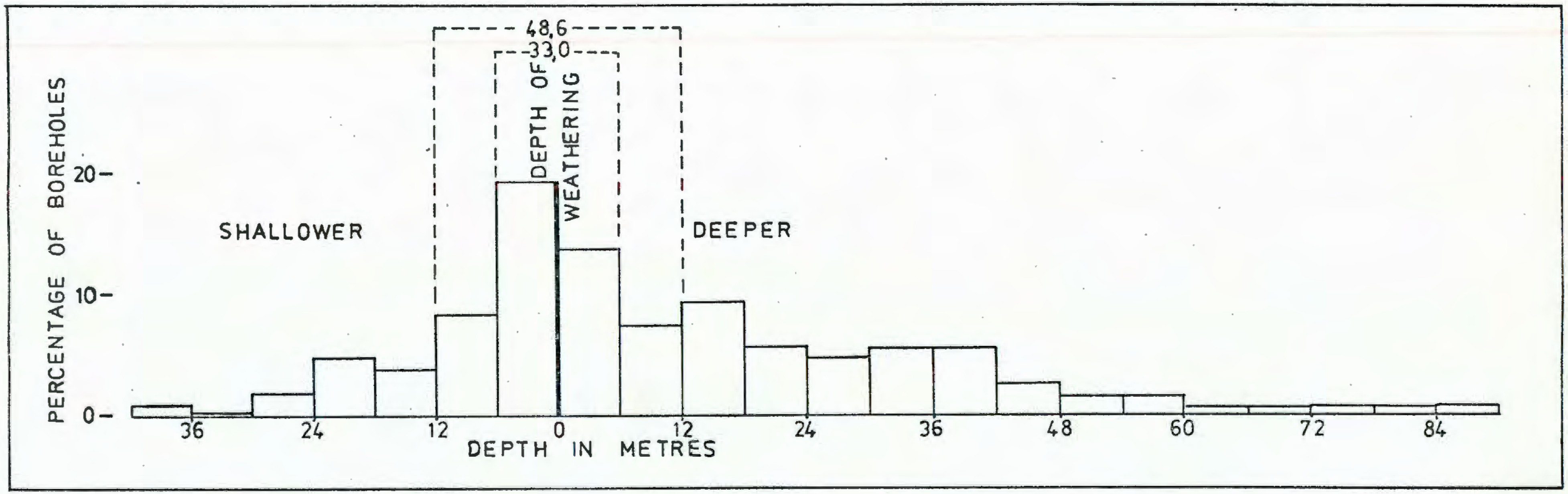
In 39 per cent of the boreholes water was struck shallower than the depth of weathering, compared to 33 per cent in the quartzitic sediments. 33 per cent of the boreholes yielded water within 6 m of the depth of weathering, and 57,8 per cent within 12 m shallower and 18 m deeper than this depth.(Fig.35)

The difference in the hydrological properties of the quartzitic sediments and the granitised sediments of the Kheis System is, therefore, surprisingly small. Both can be regarded as good aquifers.

6.2.3 WILGENHOUT DRIFT SERIES

This formation consists of well-sheared lava, schist and reddish arenaceous sediments. The rockswere intensively deformed by folding and shearing, probably by the 1 000 m.y. old orogeny (Nicolaysen and Burger, 1965). The Wilgenhout Drift Series occurs on both sides of the Orange River, approximately 50 km east of Upington, and in the Richtersveld, and occupies relatively small areas. The predominant rock-type is the green sheared lava, but north of the Orange River schists are common. In this area a rock called tillite by Du Toit (1968) and breccia by Du Toit (1954) is also found intercalated with the sediments.

Although a fair number of boreholes have been drilled in the



F<u>IG.35</u> - HISTOGRAM OF DEPTH AT WHICH WATER WAS STRUCK RELATIVE TO THE DEPTH OF WEATHERING, GRANITISED SEDIMENTS OF THE KHEIS SYSTEM, N.W.CAPE PROVINCE.

soft sheared lava and the schist, most of them were drilled by private drills and it was impossible to obtain relative statistical information. The percentage of successful boreholes is relatively high, and the yields good. After careful screening, the results of eight boreholes which found water in the Wilgenhout Drift Series, could be statistically analysed. All were drilled in laagtes near the Orange River and therefore the results are probably more favourable than for the series as a whole. Five of the eight boreholes were successful (62,5 per cent) and the average yield was 5,00 m^3/h. The average depth was 73 m and the average depth at which water was struck 47 m. The average rest level was 33 m. The ground-water in these rocks is usually brack and sometimes unfit for domestic use.

6.3 SUMMARY

1. Outcrops of the Kheis System are numerous, and the different lithological units can be studied at the surface. There is a preponderance of quartzitic sediments of which the more felspathic members have been granitised. The volcanics are predominantly andesitic and amygdaloidal.

2. Due to successive cycles of deformation, the rocks have been metamorphosed extensively, the grade of metamorphism increasing from the eastern boundary towards the north-west, but probably oscillating in the grade of metamorphism on proceeding further to the western boundary of the area. The bulk of the

rocks is granitised and is gneissic in character.

3. The occurrence of ground-water is, to a much larger extent than in the Transvaal, dependent on the topography, the rainfall, which differs widely in different portions of the area, and on the type and thickness of the surface covering or lack of it.

4. Several hydrological units have been recognised of which borehole statistics could be analysed. They are quartzitic sediments, volcanics, schist, and granitised gneissic and granulitic sediments. The percentages of successful boreholes varied between 28,6 per cent in the schist and 62,5 per cent in lava, but in both of these units the number of boreholes was too small to warrant conclusions to be drawn from these results. The average percentage of success in all of the 951 boreholes analysed, was 46,3. This is appreciably higher than the 32 per cent success of the 549 boreholes drilled in the Swaziland System in the Transvaal, in spite of the much lower rainfall in the North-western Cape Province.

This result is due to several favourable circumstances in the North-western Cape Province:

(a) Outcrops of folded and faulted strata at the surface. Infiltration of water from precipitation can therefore take place along bedding planes to the ground-water reservoir.

(b) The development of secondary structures by dynamic metamorphism, which were not closed by the products of chemical weathering, and remain permeable to ground-water.

(c) High topographical relief which facilitate the accumulation of precipitation in dams, pans, etc. where infiltration is augmented.

(d) The sparse vegetation, and the fact that it is mainly xerophytic. Surface flow is therefore relatively higher, and less water is transpirated than in the North-western Transvaal.

5. These results would be considerably improved if all the borehole sites could be selected after careful consideration of the topographical, geological, structural and geophysical data available in the area in which water is required. Too many sites are still selected in places which are topographically and positionally favourable for the consumer instead of taking the hydrological properties of the site into consideration.

7. GROUND-WATER IN THE DOMINION REEF SYSTEM AND THE SOETLIEF FORMATION

7.1 THE DOMINION REEF SYSTEM IN THE NORTH-WESTERN TRANSVAAL

7.1.1 OCCURRENCE

7.1.1.1 DISTRIBUTION

The basic and acid lavas, and the intercalated sediments, associated with the Dominion Reef System in this area, occur as a relatively narrow but well-defined belt of 1,5 to 5 km in width. This belt forms broken ground and borders the Archaean Formations on the south-west, south and south-east. On the south-west and south it is intruded by granite and basic rocks of the Gaberone Complex, and is covered by recent deposits so that outcrops are discontinuous, but are found over a wider area than further to the east. The Dominion Reef rocks are not prominent in this area. To the south-east they occur in the foothills of the more prominent Witfontein Ridge formed by the Dolomite Series of the Transvaal System. From latitude 24°25' northwards they are covered by rocks of the Transvaal System, the Bushveld Igneous Complex, and the Waterberg System.

7.1.1.2 LITHOLOGY

On the south-east and east of the Archaean Formations, the lower horizon consists of fairly thick quartzite, sandstone, grit and conglomerate, usually reddish in colour. Dips are between 25° and 40° away from the dome formed by the Archaean Granite. From Schoongezicht 446 to the west sediments are covered by alluvium, but crop out again on Rustenburg 476 and Bethanie 465. Here the dip is not as high as further to the east, being approximately 12° south. Shale and slaty rocks associated with the arenaceous sediments were usually seen only in borehole samples.

Overlying the sediments are basic and acid lavas. The bas lava is not well-exposed and weathers more easily than the overlying acid lava. It is often amygdaloidal, and is andesitic to basaltic in composition. The acid lava forms more conspicuous outcrops. Although felsitic types are also found, the bulk of these lavas consist of quartz-porphyry. On the farms Laastepoort 840 to Schots 488, the amygdaloidal basic lava directly overlies the Archaean Granite and Swaziland System. Sediments and acid lavas (mostly quartz-porphyry) follow, but due to the low dips and discontinuous outcrops, it is not clear whether there are several horizons of the sediments, or a duplication of a single horizon due to folding and topographical relief.

Further to the west the Dominion Reef System crops out in the Marico District up to the Botswana border. As in the Laastepoort 840 area the basic lava is found at the base, but it is followed by acid lava, and then by the arenaceous sediments. In the overlying rocks correlated with the Ventersdorp System the succession from base to top is sediments, felspar-porphyry, felsitic acid lava, and basic lava. Sometimes a second sedimentary horizon had developed between the acid and basic lava.

7.1.1.3 TOPOGRAPHY

The Dominion Reef System occupies the slightly higher ground at the rim of the dome formed by the Archaean Formations. Valleys are generally clearly-defined, and occur as gorges in the more resistant arenaceous sediments and acid lavas. To the south-east the Black Reef Series overlies the acid lava, usually forming a well-defined escarpment. The basic lava forms the more level portions between the acid lavas and sediments, and on Laastepoort 840, the plain to the north of the low ridge formed by the latter. Several faults, cutting approximately at right angles across the strike of the formation, are seen on the south-eastern edge of the dome formed by the Archaean Formations.

7.1.2 GROUND-WATER

7.1.2.1 SELECTION OF BOREHOLE SITES

Although outcrops of acid lava, porphyry, and arenaceous sediments, were frequently seen, they usually cropped out on high ground, where they formed ridges and water sheds. It was, therefore, usually necessary to use:

(a) the magnetometer to trace dykes, and the contact between intrusive granite and lava, or between lava and sediments, and

(b) the electrical resistivity apparatus to determine the depth of weathering in the lava or sediments in this formation. By resistivity depth probes it was sometimes possible to determine the relative degree of weathering in the lavas. This is important, as the weathered material was sometimes too clayey to yield adequate supplies of ground-water.

In general considerably less geophysical work was necessary for the selection of borehole sites in this formation than in the Swaziland System, due to the fact that more information could be gleaned from surface geology and topography. Surveys could be limited to pans, laagtes and thicker growths of bush or trees. The latter indicated contacts between different horizons, intrusive contacts of dykes, or intrusive contacts of the Gaberone Complex.

7.1.2.2 STATISTICS

From the cumulative graph of yield as a function of the percentage of the total number of boreholes (Fig. 36) it is seen that 70 per cent of the boreholes were failures. A yield of 1,36 m^3/h is currently regarded as the minimum that can be used economically in this area. Only 16,7 per cent of the boreholes in the Dominion Reef System were therefore of any economic value. This percentage is extremely low, and can largely be attributed to the very shallow weathering in the lava, and the fact that the Dominion Reef System, sometimes with the overlying Black Reef and Dolomite Series, forms the watershed

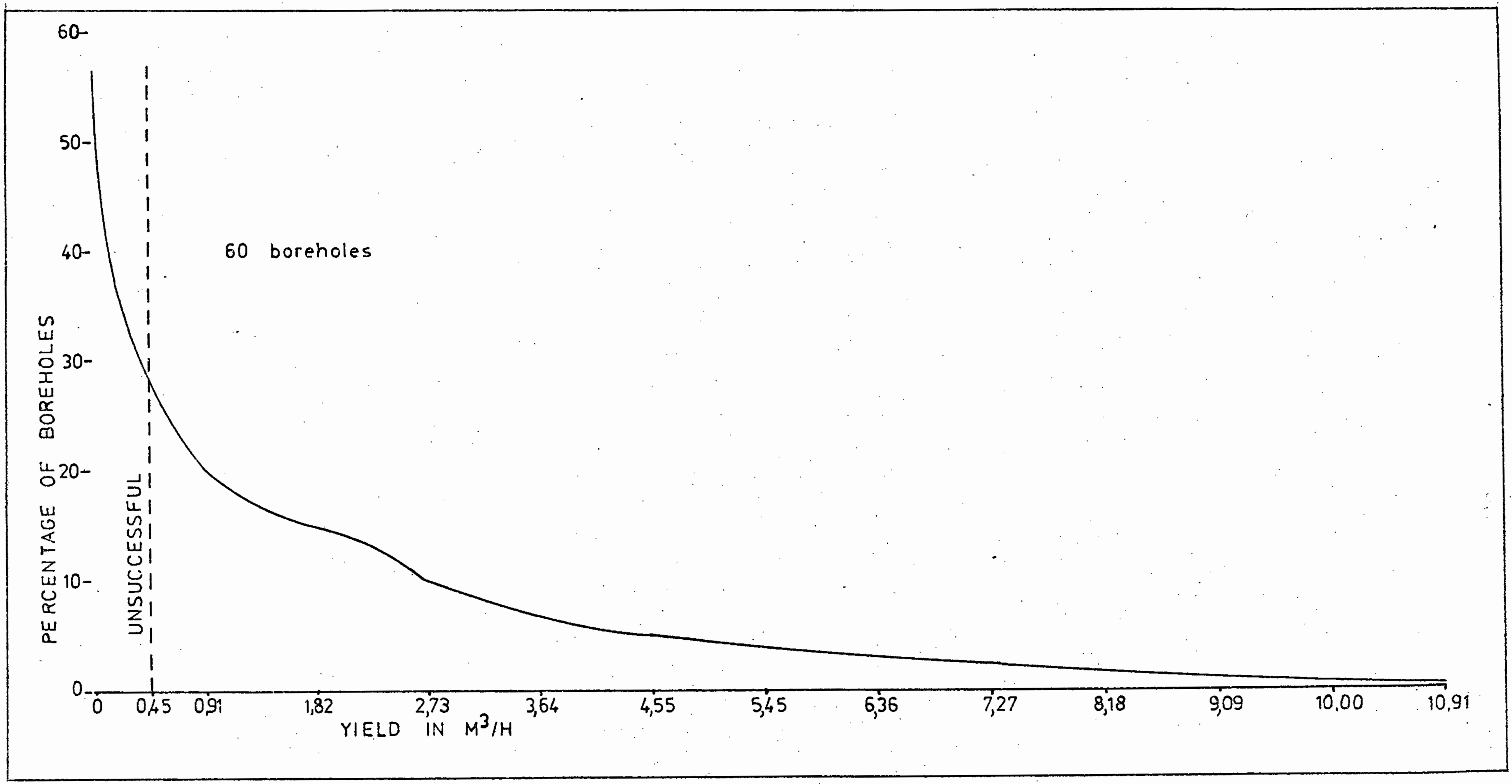


FIG.36 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF THE TOTAL NUMBER OF BOREHOLES, DOMINION REEF SYSTEM, N.W. TRANSVAAL.

between north-flowing and south-flowing laagtes and rivers. The exceptions are the two major rivers, the Marico and the Crocodile, which cut through these rocks by means of narrow poorts as at Laastepoort 840.

From the histograms of the depth at which water was struck (Fig. 37(a)) it can be seen that nearly 90 per cent of the water was struck at depths shallower than 61 m. For successful boreholes the percentage was even higher, although only one successful supply was struck at a shallower depth than 15 m. 71,5 per cent of the successful supplies were struck between 30 and 61 m.

The histograms of the rest levels (Fig. 37(b)) show that there is very little difference in the rest levels and the depths at which water was struck. 93,5 per cent of the rest levels are shallower than 61 m (94,1 per cent in the case of successful boreholes), which is only a slightly higher percentage than that of the depths at which water was struck between the same limits. This result is due to the fact that the ground-water is found at relatively shallow depths in unconfined aquifers. The high percentage of acid and porphyritic lava, and of arenaceous sediments, means that relatively little clay, which can act as an aquiclude, is formed.

According to the results of resistivity surveys at 45 boreholes, the apparent resistivity at the ground-water rest level in the Dominion Reef System, was less than 20 ohm m in only three

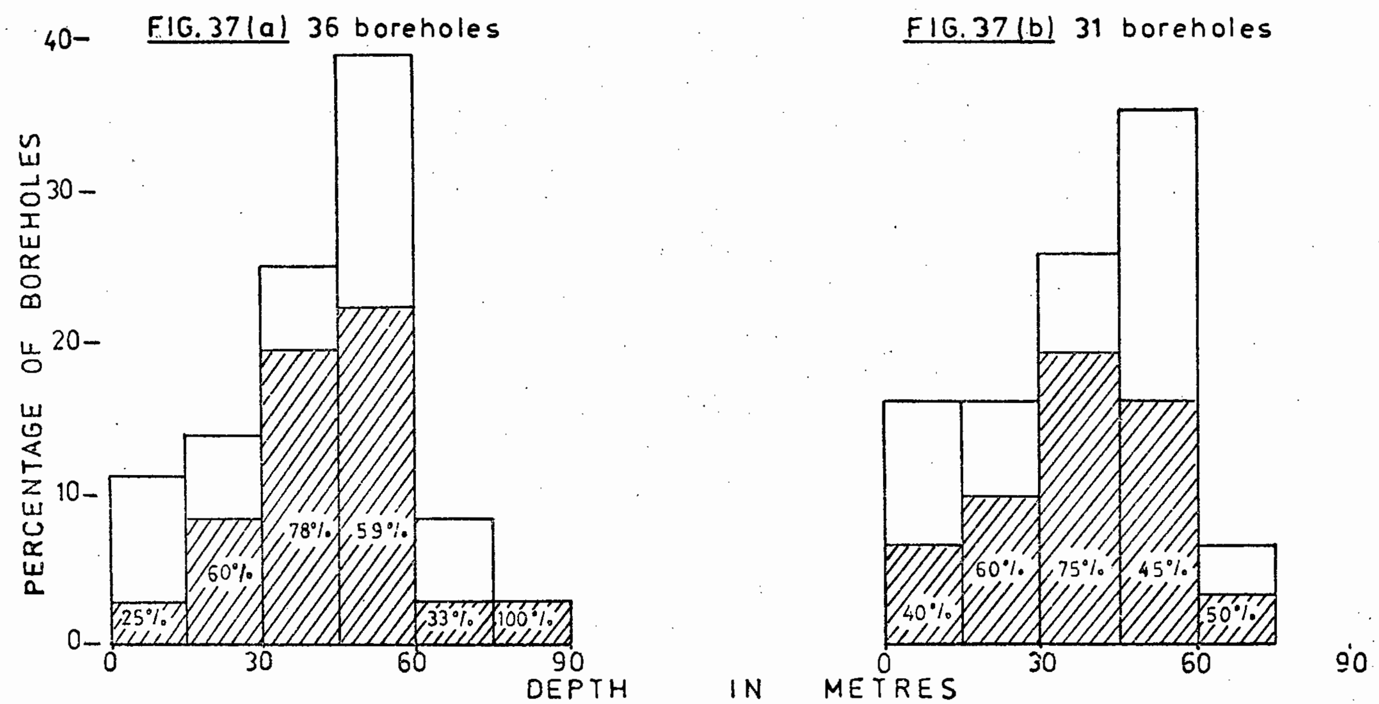


FIG.37 - (a) HISTOGRAM OF DEPTH AT WHICH WATER WAS STRUCK IN BOREHOLES (Successful boreholes shaded);
(b) HISTOGRAM OF REST LEVELS IN BOREHOLES (Successful boreholes shaded); DOMINION REEF SYSTEM, N.W. TRANSVAAL.

boreholes. The yields of boreholes in which the apparent resistivity was less than 40 ohm m were very low (Fig. 38(b)). Pronounced high yields were found at apparent resistivities of 80 to 120 ohm m. At higher resistivities up to 180 ohm m only a few boreholes were successful, and these yielded water from secondary structures in the arenaceous sediments. The percentage of successful boreholes varied between 33 and 43 per cent for resistivities between 20 and 180 ohm m (Fig. 38(a)). Where apparent resistivity at the water level was higher than 180 ohm m, no successful boreholes were drilled.

If only boreholes with an "economic yield" is taken into account, no boreholes in which the apparent resistivity at the water level was higher than 120 ohm m could be used. A decided peak of 43 per cent of economically successful boreholes, was found between 80 and 120 ohm m (Fig. 38(a)). In the case of successful boreholes (yield more than 0,45 m^3/h) this peak is not so well defined; and the percentage of success remains relatively high between 20 and 180 ohm m.

The depth of weathering was recorded in 32 boreholes in which water was struck. In nineteen of these boreholes water was struck deeper than the depth of weathering, 74 per cent of it in cracks and joints within six m of this depth. In thirteen boreholes water was struck between 1 and 24 m above the depth of weathering. Of the ninteen successful boreholes, ten struck

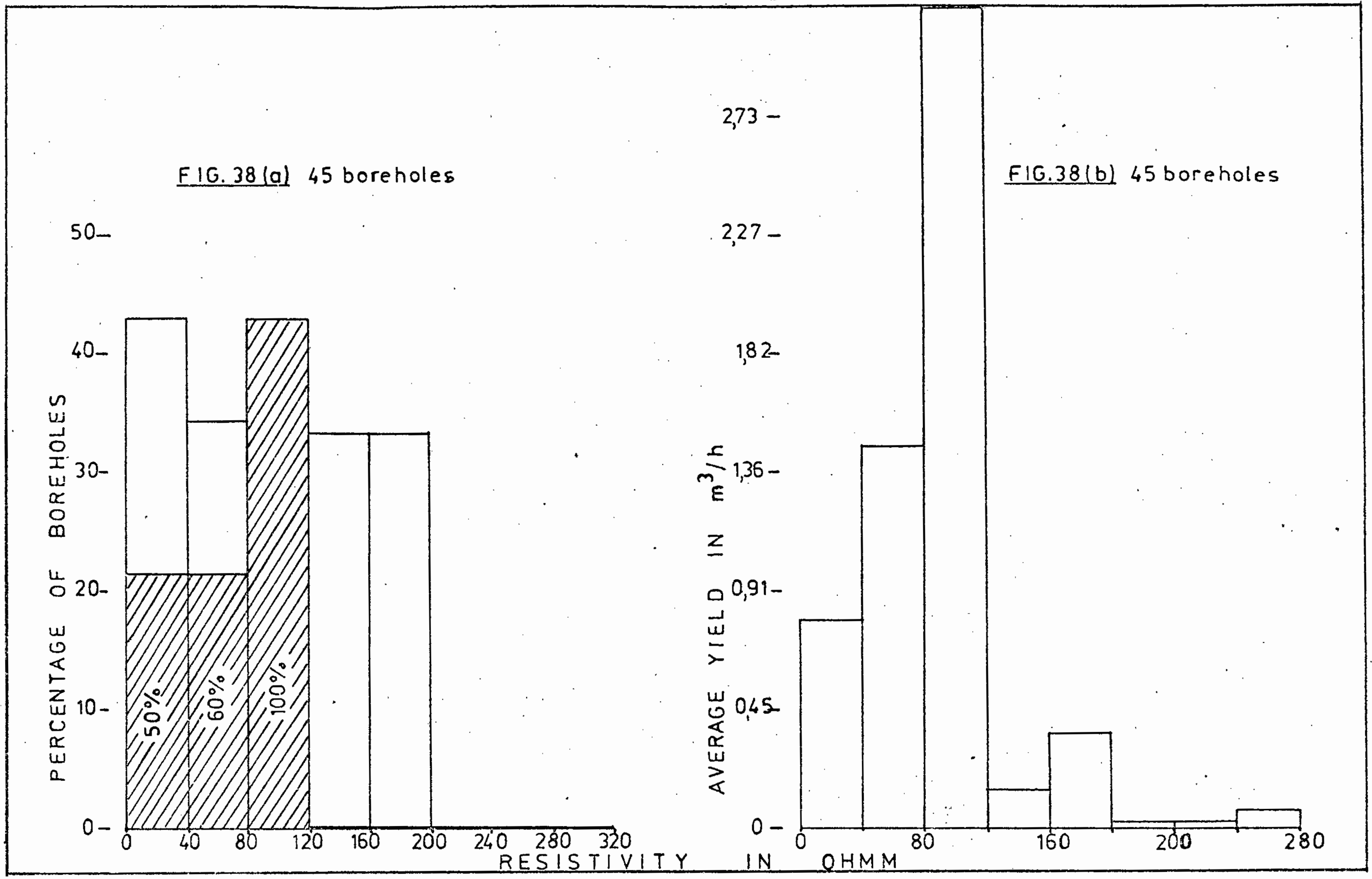


FIG.38 - (a) HISTOGRAM OF PERCENTAGES OF SUCCESSFUL BOREHOLES AS A FUNCTION OF APPARENT RESISTIVITY AT THE GROUNDWATER REST LEVEL (Boreholes yielding > 1,36 m^3/h shaded);

(b) HISTOGRAM OF THE AVERAGE YIELD OF BOREHOLES AS A FUNCTION OF APPARENT RESISTIVITY AT THE GROUNDWATER REST LEVEL; DOMINION REEF SYSTEM, N.W.TRANSVAAL.

water deeper than the depth of weathering. Of these 80 per cent struck water within 6 m of this depth. The two boreholes in which water was struck at a greater depth, were drilled in quartzite and sandstone, which have many more permeable secondary structures than the lavas.

It is therefore essential to drill to a depth of at least 6 m deeper than the depth of weathering to find adequate supplies of ground-water. The depth of weathering can be determined with good accuracy in the Dominion Reef System by means of electrical depth probes.

7.2 THE SOETLIEF FORMATION IN THE CAPE PROVINCE

7.2.1 OCCURRENCE

7.2.1.1 DISTRIBUTION

The Soetlief Formation in the North-western Cape Province occurs in three outcrop areas:

(a) In a triangle between the Orange River near Koegas, the Buchuberg Dam, and the vicinity of Draghoender near Marydale. In this area the formation was divided by Leube (1959) into a Lower and an Upper Soetlief Series.

(b) Along the Doornberg Fault south of the area mentioned above, in a south-southeasterly direction. The outcrops are generally confined to a narrow strip west of the Doornberg Range, due to high dips. This strip reaches its greatest width along the road between Prieska and Marydale. It is wedged out against the Doornberg Fault between Fransenhof and Uitspanberg, to the west of Prieska.

(c) To the east of Sodium Salt Pan and Omdraaisvlei in the Kuip Hills, where it was formerly regarded by Du Toit (1907) to consist of two series viz. the Zoetlief Series and the Kuip Series.

7.2.1.2 LITHOLOGY

Both in the northern and south-eastern areas, the lower horizons consist mainly of quartz-porphyry, felsitic lava, andesitic lava, and pyroclastic rocks, with very subordinate dolomitic limestone and quartzite. The andesitic lava, both massive and amygdaloidal, is very well-developed in the northern area.

In the central area the succession consists of quartz-porphyry, felsitic lava, and andesitic lava, with very subordinate conglomerate lenses. These are found near the top of the succession, underlying the Black Reef Series of the Transvaal System, and separated from it by andesitic lava.

The bulk of the sediments consists of quartzite, arkose, and conglomerate, with subordinate shaly or schistose rocks. The quartzites are medium to fine-grained, and sometimes felspathic.
The greatest development of quartz-porphyry was seen on the farm Deelpan to the west of Prieska. It underlies the basic lava from Kaboom to the south. The acid lavas were found from the

farm Witvlei to the south, and they are prominent in the Kuip area. On the farm Schalksdrift lavas described by Leube (1959) as acid, were found to be of intermediate composition. They are of the same type as found by Du Toit (1907) in the Kuip area. In the last-named area the succession is involved, probably due to overfolding and duplication. The small outcrop area, the cover of Karoo rocks, and the effect of several periods of folding and subsequent development of cleavage and lineation, obliterating the original bedding planes and lava flows, made it almost impossible to unravel the succession.

7.2.1.3 TOPOGRAPHY

The Soetlief Formation usually forms broken country viz. the Kuip Hills in the south, low hills and ridges on Fransenhof and Deelpan, the foothills of the Doornberg Range on Witvlei and Geelbeksdam, and the highly-dissected country along the Orange River between Koegas and the Buchuberg Dam. It is only on the farms Blinkfontein and Zeekoebar that the andesitic lava forms a plain with low relief.

In the Soetlief Formation outcrops are generally numerous, but contacts are often obscured by deposits of rubble. Near the Orange River valleys are narrow and deeply-incised, and the relief is usually high.

7.2.2 GROUND-WATER

7.2.2.1 OCCURRENCE

Ground-water is usually found at a shallow depth in the Soetlief Formation. Unweathered lava forms an impenetrable floor below the surface covering of calcrete and the thin belt in which joints and other secondary structures penetrate to a shallow depth in the lava. Ground-water is sometimes struck in the calcrete on top of the lava, but more often in the weathered or semi-weathered zone with secondary structures. Good supplies are also found near the contacts of dykes of which a relatively large number strike north-south to NW-SE in the northern area of outcrop of the Soetlief Formation; near contacts with the intrusive Geelbeksdam Granite; and along faults or shear-zones.

Very few of the boreholes in the lava have dried up, although several of them decrease in yield during droughts due to a lowering of the ground-water rest level. On Paauwpan the rest level drops by approximately 15 m during droughts, but the boreholes are recharged soon after a good rainfall, due to the highly permeable covering of calcrete.

In the Kuip Hills, where there is a relatively rapid succession of basic and acid lavas, quartz-porphyry, arenaceous sediments and dolomitic limestone it is usually easy to select sites where boreholes will intersect open jounts or bedding-planes. Yields

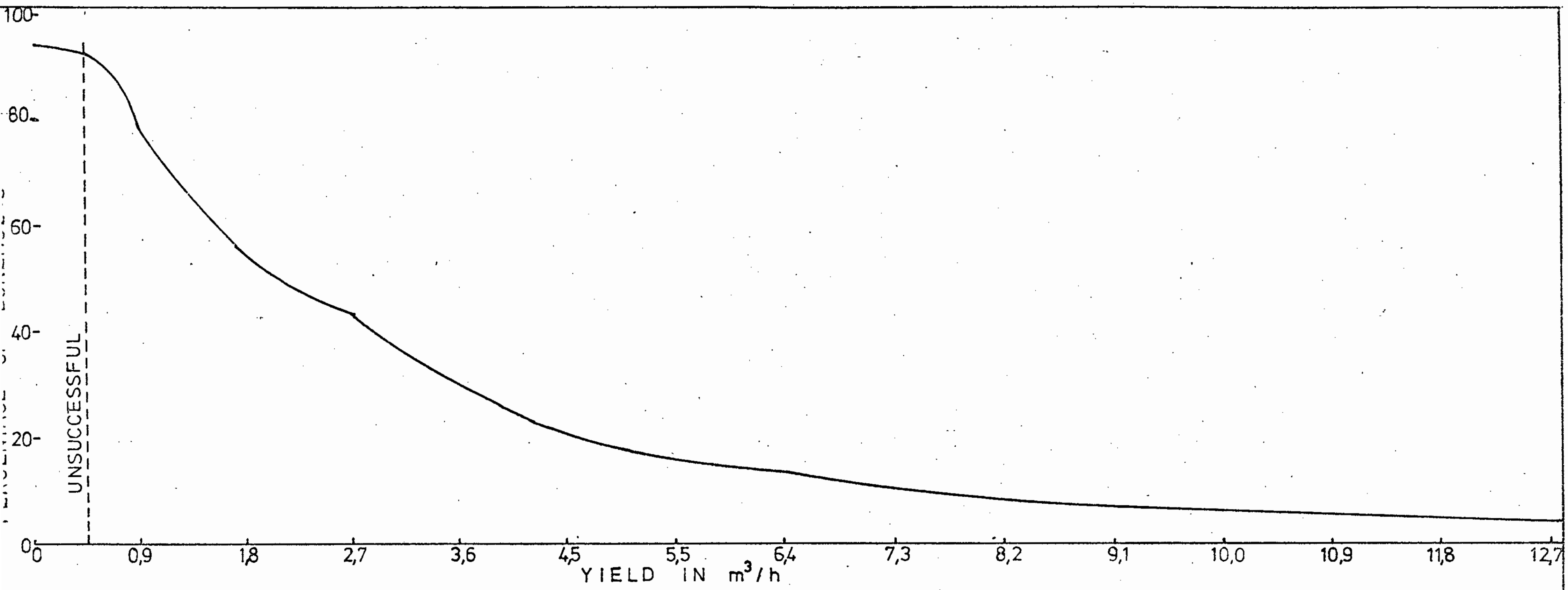


FIG.39 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF BOREHOLES, SOETLIEF LAVA, N.W.CAPE PROVINCE.

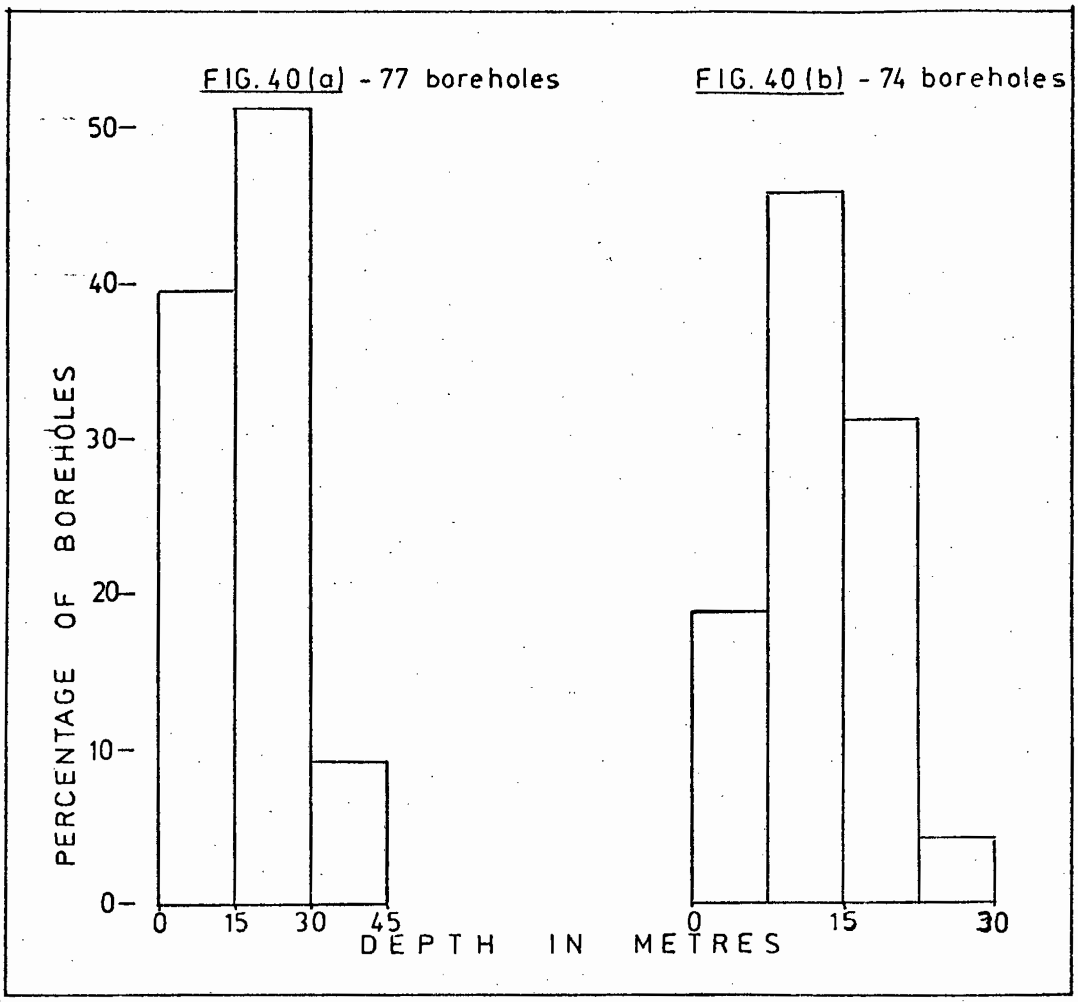


FIG.40 - (a) HISTOGRAM OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE NUMBER OF BOREHOLES;

(b) HISTOGRAM OF REST LEVELS AS A PERCENTAGE OF THE NUMBER OF BOREHOLES; SOETLIEF LAVA, N.W.CAPE PROVINCE.

From the histograms (Fig. 80(a) and (b)) can be seen that the highest average yield of 2,25 m^3/h in five boreholes was obtained where the apparent resistivity below the ground-water rest level was less than 100 ohm m. The percentage of successful boreholes was 80 or more for resistivities up to 200 ohm m, above which it dropped to 33,3 per cent in six boreholes, and the average yield to 0,41 m^3/h.

The quality of the water is generally good, as can be expected from such shallow ground-water reservoirs.

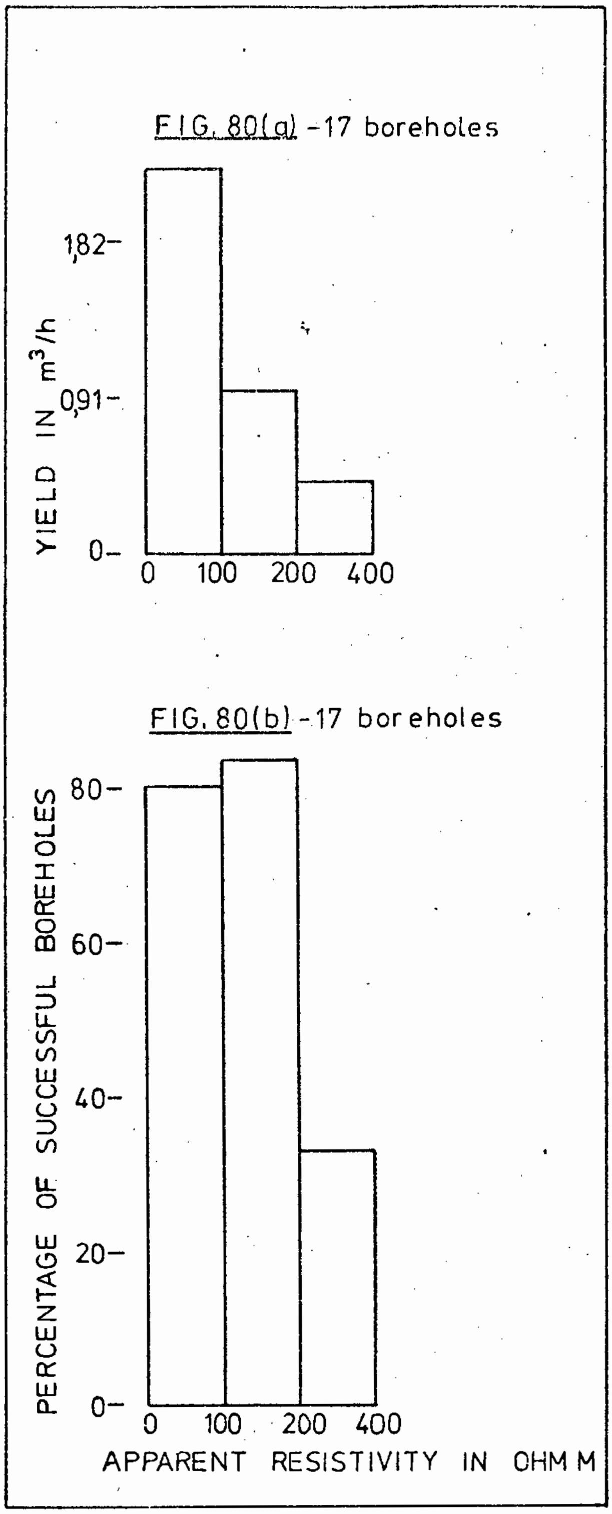


FIG. 80 - HISTOGRAMS OF THE APPARENT RESISTIVITY AT THE REST LEVEL AS A FUNCTION OF THE (a) YIELD OF BOREHOLES; (b) PERCENTAGE OF SUCCESSFUL BOREHOLES; SOETLIEF AND MARYDALE LAVA, N.W. CAPE PROVINCE.

8. GROUND-WATER IN GRANITE AND GNEISS

8.1 TRANSVAAL

Although no geochronological age has been determined for the Archaean Granite north of the Witfontein Ridge in the Rustenburg District, it must be older than the Dominion Reef System. The granite forms a dome-like outcrop area with the Dominion Reef and younger rocks overlying it, and dipping away from the dome. No outcrops have been found where this granite cuts any of the Dominion Reef volcanics or sediments. This granite must therefore be older than the Pietersburg Granite to the north-east, and the granite of the Gaberone Complex, which are both post-Dominion Reef. It must, however, be younger than the Swaziland System, because it is intruded into these rocks. Part of the granite could be granitised members of the Swaziland System.

8.1.1 OCCURRENCE

8.1.1.1 DISTRIBUTION

This granite occurs in the North-western Transvaal in a single compact area between east longitudes 26°26' and 27°23', and south latitudes 24°04' and 24°48'. The Marico River forms the western boundary and the ridges formed by the Dominion Reef System and the Transvaal System the southern and eastern boundaries. The

Waterberg System and alluvium cover it to the north. The Swaziland System, into which the granite is intruded, occupies approximately 40 per cent of the area described above. The whole of this area is covered by calcrete, sand and alluvium except for occasional outcrops of granite in gullies or along riverbanks.

8.1.1.2 TOPOGRAPHY AND LITHOLOGY

The whole area is flat, without any features which can be attributed to rock-outcrops. Near the Crocodile River, in the more undulating country sloping towards the river-bed on Beaufort 86, Crauseburg 198, and Koedoesfontein 529, a light-coloured coarse-grained granite was seen, usually coloured off-white, light-grey or reddish. It was a muscovite-bearing granite with very little biotite. With increase of biotite it changes to a gneiss which is usually finer-grained and darker in colour. In a well on Holland 445 the grey biotite-gneiss was seen, and in an excavation on Laastepoort 840 the gneiss was banded with the darker layers fine-grained, and the lighter-coloured layers more coarse-grained. According to evidence from boreholes slightly more than 60 per cent of this area is underlain by granite.

8.1.2 STATISTICS

Information was collected of 730 boreholes which had been drilled in the Archaean Granite. Of these only 37,6 per cent were successful(having yields of 0,45 m^3/h or more), and more than 43 per cent of the boreholes were dry. A cumulative graph of the yield of the boreholes as a percentage of the total number of boreholes is shown in Fig. 41. If the economic supply of 1,36 m^3/h is taken as criterion, only 28,2 per cent of the boreholes can be considered to have useful supplies. Of the economic supplies a surprising 39 per cent yielded 4,54 m^3/h or more, and the highest yield recorded was more than 22 m^3/h. The average yield of successful boreholes was 4,2 m^3/h, which is an excellent supply in this formation and area.

From the cumulative graph of the percentage of the total number of boreholes exceeding a given depth (Fig. 42) can be seen that 93,5 per cent of the boreholes were deeper than 30 m, but only 7,4 per cent deeper than 91 m. In the case of successful boreholes, 89 per cent were drilled to depths ranging between 30 and 91 m.

In 88,8 per cent of the boreholes the depth of weathering was less than 61 m (Fig. 43). From this histogram and from Fig. 42, can be calculated that boreholes were drilled to an average depth of 24 m in solid rock. By comparing this figure with the depths at which water were struck (Fig. 44(a)) it is found that in 51,4 per cent of the boreholes the depth of weathering was shallower than 30 m, whereas water was struck within this depth range in only 15,0 per cent of the boreholes. Many of the failures in the granite must, therefore, be attributed to the lack of weathering, which was often not deep enough to yield ground-water.

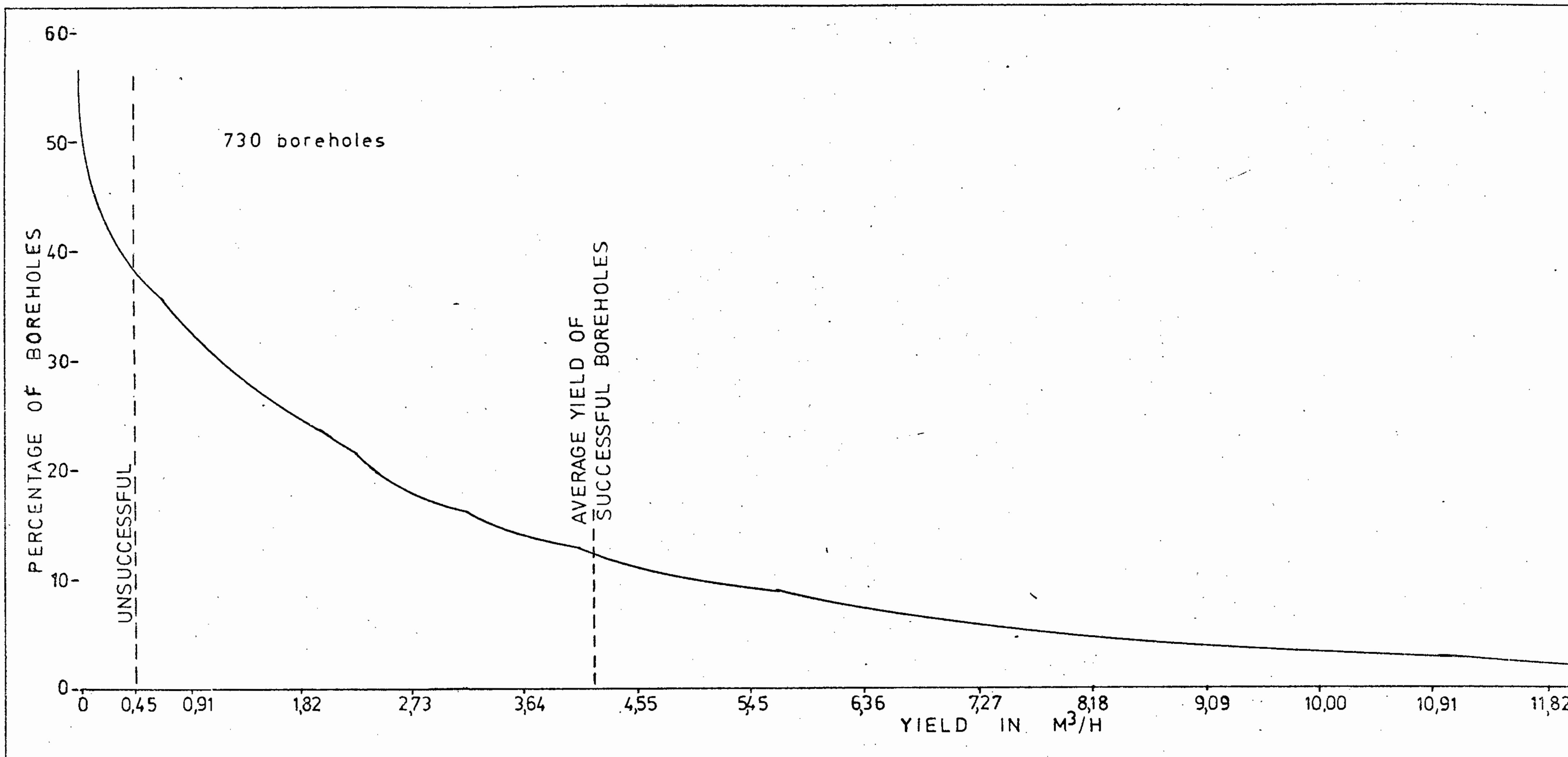


FIG. 41 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF THE NUMBER OF BOREHOLES, ARCHAEAN GRANITE N.W.TRANSVAAL.

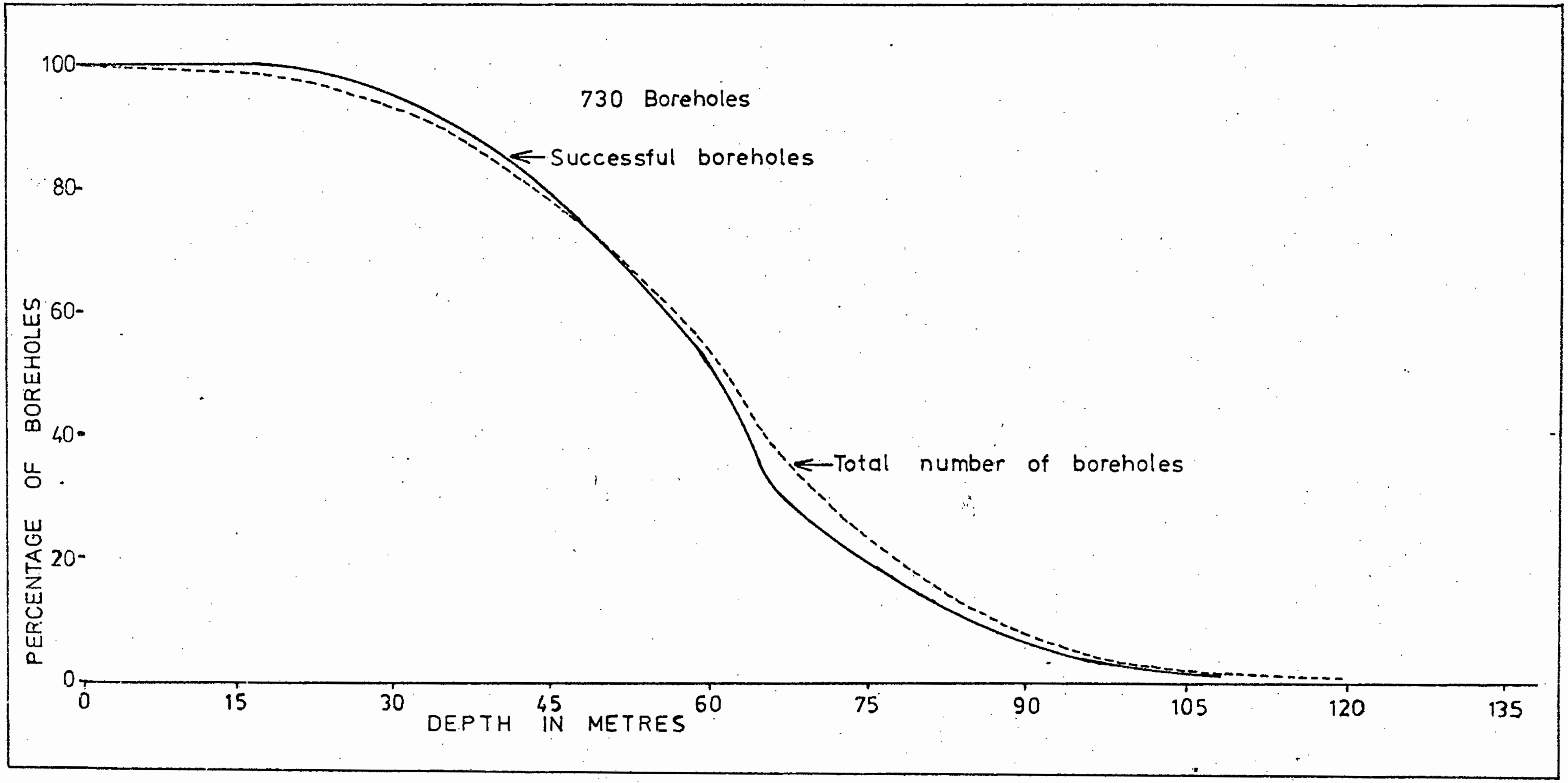


FIG. 42 - CUMULATIVE GRAPHS OF THE PERCENTAGE OF BOREHOLES EXCEEDING A GIVEN DEPTH, ARCHAEAN GRANITE, N.W. TRANSVAAL.

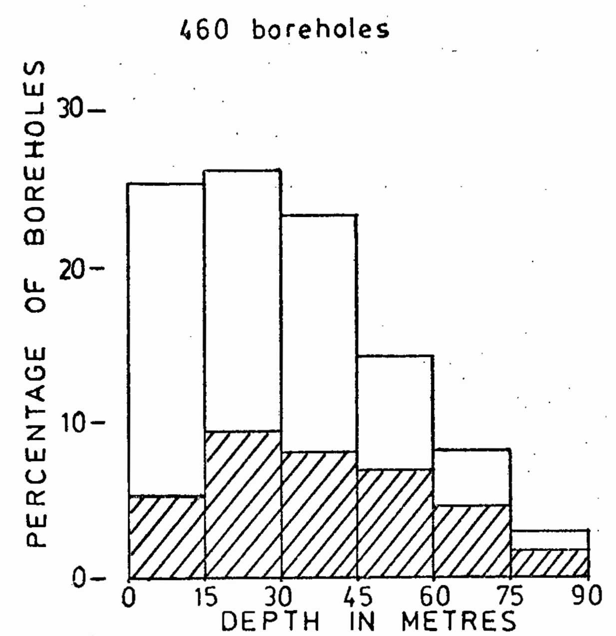


FIG. 43 - HISTOGRAM OF DEPTH OF WEATHERING RELATIVE TO THE PERCENTAGE OF THE NUMBER OF BOREHOLES, ARCHAEAN GRANITE, N.W. TRANSVAAL. (Successful boreholes shaded)

It is significant that the percentage of successful boreholes increased with increased depth of weathering, as can be seen in Fig. 43.

According to the above percentages, water was struck deeper than 30 m in 440 boreholes. Only 280 boreholes were weathered to this depth. Water was, therefore, often struck in joints and cracks in unweathered, or cracked granite, below the depth of chemical weathering. From Fig. 45 can be seen that in some of the boreholes even the rest levels were in unweathered granite. Only 29,1 per cent of the rest levels were shallower than 61 m. In the case of successful boreholes (Fig. 44(b)) 74,9 per cent of the boreholes yielded water before a depth of 61 m was reached, and 93,5 per cent before a depth of 76 m. There is no significant difference between the depths at which water was struck in successful and unsuccessful boreholes.

In 85,9 per cent of the boreholes the rest levels were between 15 and 61 m below the surface (Fig. 45). Although no surface elevations were measured, the relief in the granite was very low. Between Engeland 862 and Cumberland 779, the gradient was 1:566, as stated in chapter 2.1.1. The differences in ground-water rest level were therefore a measure of the differences in absolute elevation of the water level above m.s.l. The fact that such a large percentage of the water levels were concentrated between 15 and 61 m below the surface, indicated that there are probably very few aquifers in isolated basins; and that wide-spread leakage occurs

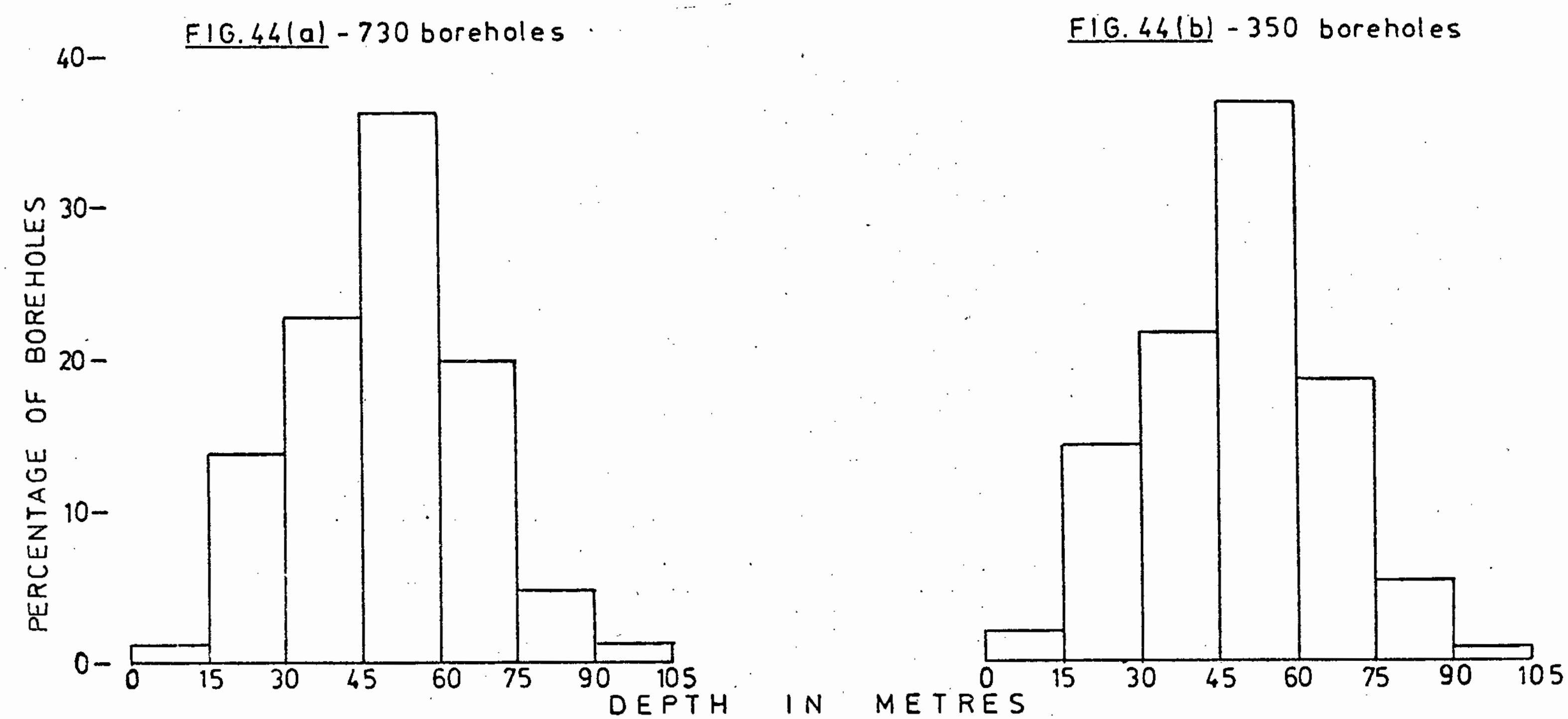


FIG. 44 - (a) HISTOGRAM OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE TOTAL NUMBER OF BOREHOLES;

(b) HISTOGRAM OF DEPTH AT WHICH WATER WAS STRUCK IN SUCCESSFUL BOREHOLES; ARCHAEAN GRANITE, N.W. TRANSVAAL.

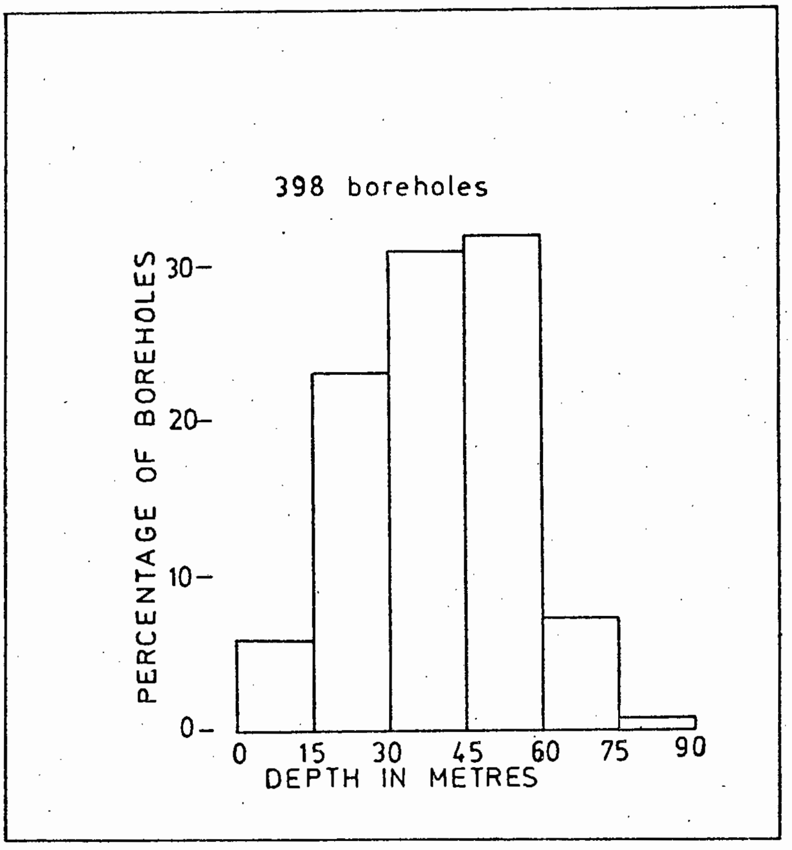


FIG.45 - HISTOGRAM OF REST LEVELS AS A PERCENTAGE OF THE NUMBER OF BOREHOLES, ARCHAEAN GRANITE, N.W. TRANSVAAL.

between the basins of weathering. The depth of weathering was not deep (Fig. 43) so that the floor of solid rock must be a nearly flat surface having undulations with low slopes and low relief. The rock surface must have a gentle regional slope to the north or north-west. This inferred leakage of ground-water, causing a general spread of ground-water over the whole area can be one of the reasons for the scarcity of economically useful boreholes. It can also be the cause of the relative slow and small variations in ground-water rest levels which will be discussed later.

A histogram of the depth at which water was struck relative to the depth of weathering is shown in Fig. 46. In 27,7 per cent of the boreholes, water was struck within 3 m of the depth of weathering. This can be called the semi-weathered zone between the weathered granite and unweathered rock containing only secondary structures such as cracks and joints. Only 20,7 per cent of the boreholes yielded water in the weathered rock at shallower depths, whereas in 51,6 per cent of the boreholes water was struck in joints and cracks in unweathered rock. A remarkable 24,9 per cent of the boreholes yielded water more than 18 m below the depth of weathering. It is, therefore, not realistic to condemn a borehole as unsuccessful unless it is drilled to a depth of 20 to 30 m below the depth of weathering. It is possible that many of the unsuccessful boreholes in this area are boreholes which have been abandoned at too shallow a depth, because the drill

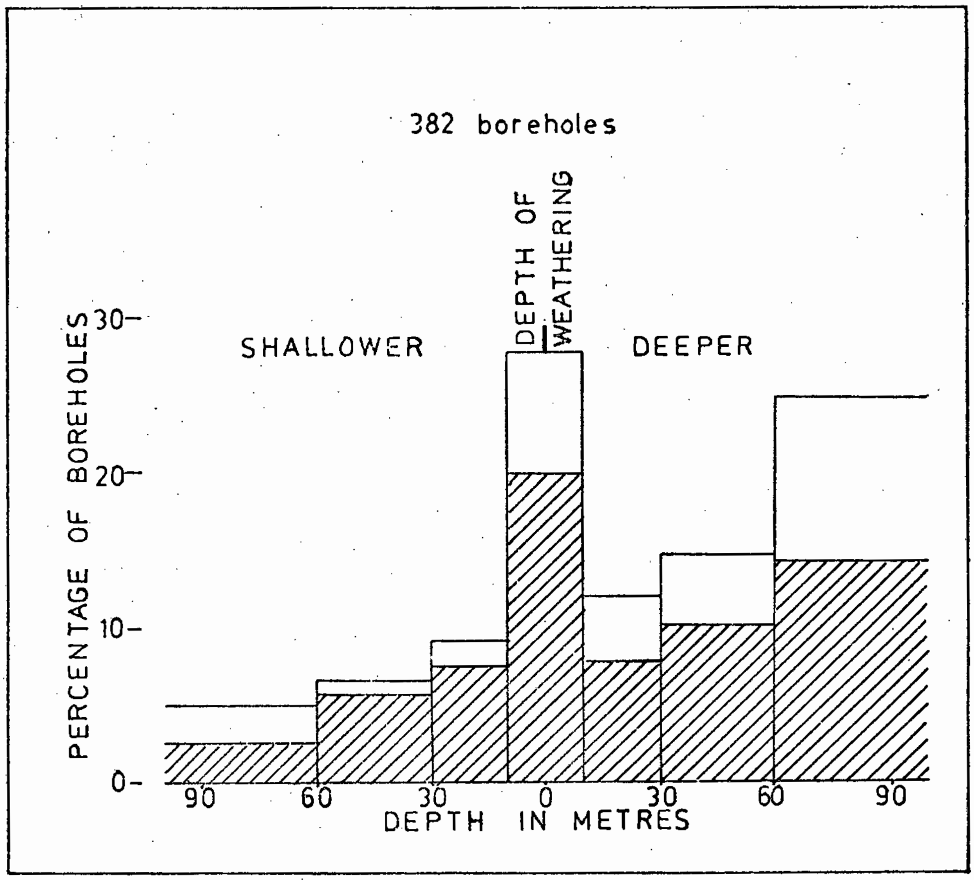


FIG.46 – HISTOGRAM OF DEPTH AT WHICH WATER WAS STRUCK RELATIVE TO THE DEPTH OF WEATHERING, ARCHAEAN GRANITE, N.W. TRANSVAAL. (Successful boreholes shaded)

reached unweathered rock.

It can further be deduced that:

(i) Over large areas infiltration of water to the ground-water reservoir is not sufficient to allow the rest level to rise above the depth of weathering in the granite;

(ii) On many farms the secondary structures in the granite have a large enough storage capacity to absorb infiltration, and to yield the quantity of ground-water extracted annually from the ground-water reservoir.

Due to these facts geophysical investigations to delimit the depth and extent of basins of decomposition are no guarantee that ground-water will be found. The possibility of finding cracks and joints below the area where the weathering is deeper than elsewhere, must, however, be considered to be very good. It is logical to deduce that weathering probably started along secondary structures, and the deepest weathering is usually found where there is the greatest concentration of secondary structures.

8.1.3 ANALYSES OF GEOPHYSICAL SURVEYS

8.1.3.1 ELECTRICAL RESISTIVITY

Electrical resistivity depth probes were done at 225 existing boreholes, and the apparent specific resistances at the depths at which water was struck, were determined by the empirical method as described by Enslin (1963). Graphs were drawn of apparent specific resistance as a function of yield and percentage of successful boreholes. Because the majority of the boreholes yielded water in cracks and joints below the depth of weathering, there was no direct correlation between the resistivity at the depth at which water was struck, and the yield or the percentage of successful boreholes. It was, therefore, impossible to find a range of specific resistances for which optimum yield and percentage of success were obtained.

The graph of apparent resistivity as a function of yield against specific resistance (Fig. 47(c)) was nearly parallel to the x-axis for values of the apparent specific resistance between 30 and 300 ohm m. The average yield for this range varied between 1,7 and 2,3 m^3/h. At higher apparent resistivities the yield decreased sharply but also the number of boreholes, so that this portion of the graph was not reliable. The percentage of successful boreholes (Fig. 47(a)) declined from 59 per cent at an apparent specific resistance of 40 ohm m to 31 per cent at 360 ohm m. For higher apparent resistivity the yield decreased sharply, but with the same reservation with regard to the number of boreholes as for the yield.

It can be concluded that the percentage of successful boreholes will increase if boreholes are selected only in places where weathering extends to a greater depth than the depth of the groundwater rest level. However, the average yield was higher at an

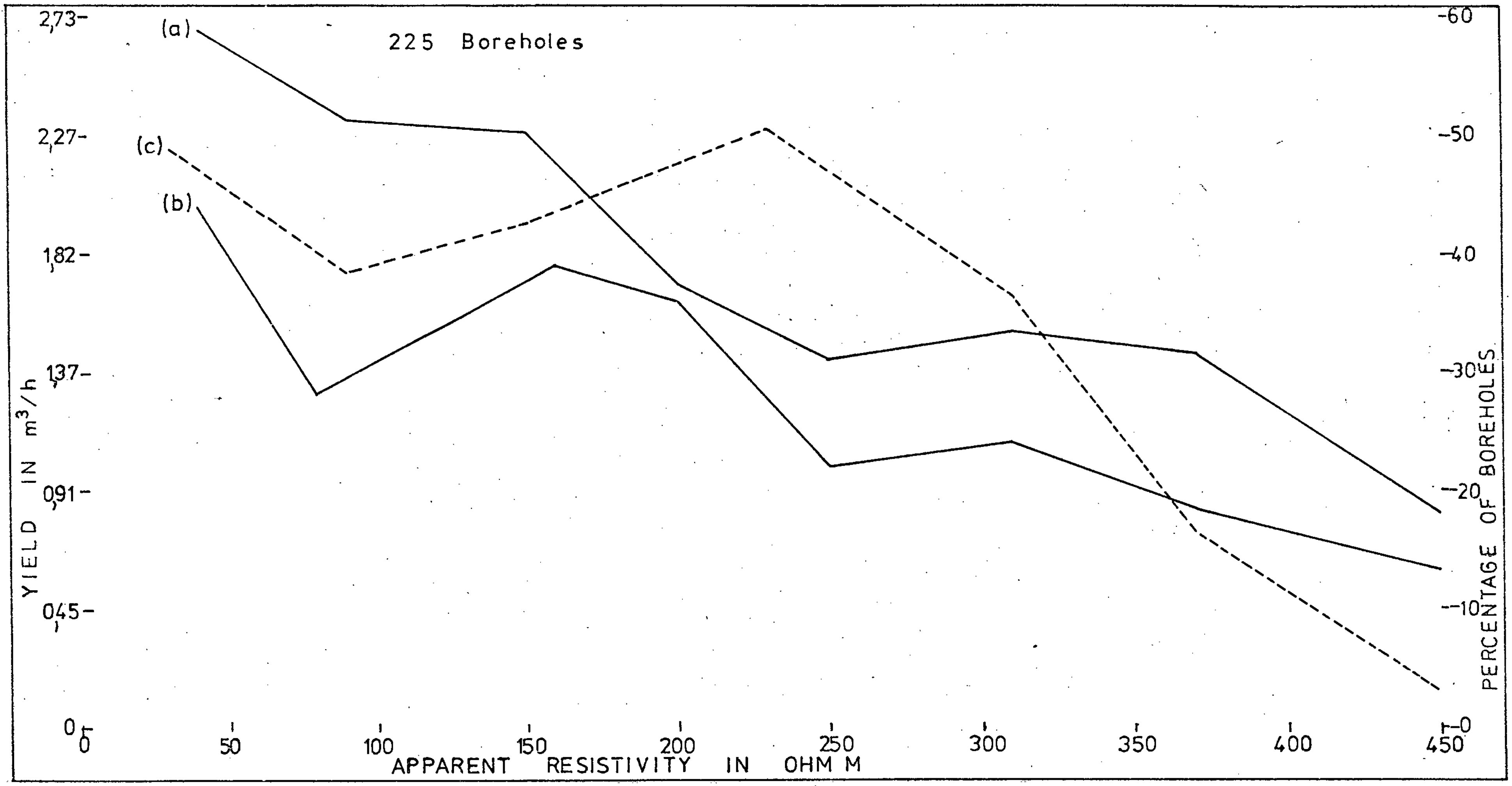


FIG. 47 - SMOOTHED GRAPHS OF APPARENT RESISTIVITY AS A FUNCTION OF:
(a) THE PERCENTAGE OF SUCCESSFUL BOREHOLES;
(b) THE PERCENTAGE OF BOREHOLES YIELDING MORE THAN 1,36 m^3/h;
(c) THE AVERAGE YIELD OF THE BOREHOLES;
ARCHAEAN GRANITE, N.W. TRANSVAAL.

apparent specific resistance of 240 ohm m than at 80 to 100 ohm m. For successful boreholes the average yield was higher for values between 100 and 320 ohm m than for values below 100 ohm m and over 320 ohm m.

No general rule for the selection of borehole sites with optimum yield can therefore be deduced from the results of the resistivity surveys, because a wide range of apparent specific resistances may yield economic water supplies.

If a yield of 1,37 m^3/h is taken as the limiting value for an economic supply (Fig. 47(b)), the highest percentage of successful boreholes was found where the apparent specific resistances were less than 60 ohm m (44 per cent). The percentage of successful boreholes dropped below 24 per cent for values of 225 ohm m and higher.

8.1.3.2 ELECTRICAL BOREHOLE LOGGING

Electrical borehole logging or coring was done in 44 boreholes drilled in granite. The specific resistances were calculated at the depths at which water was struck. The graphs of specific resistance as a function of the percentage of successful boreholes and average yield are given in Fig. 48(a) and 48(c). A very positive optimum value of the specific resistance is found at 100 to 300 ohm m both for the percentage of successful boreholes (66,7 per cent) and for the average yield (2,7 m^3/h). These results compare well with the results in the previous

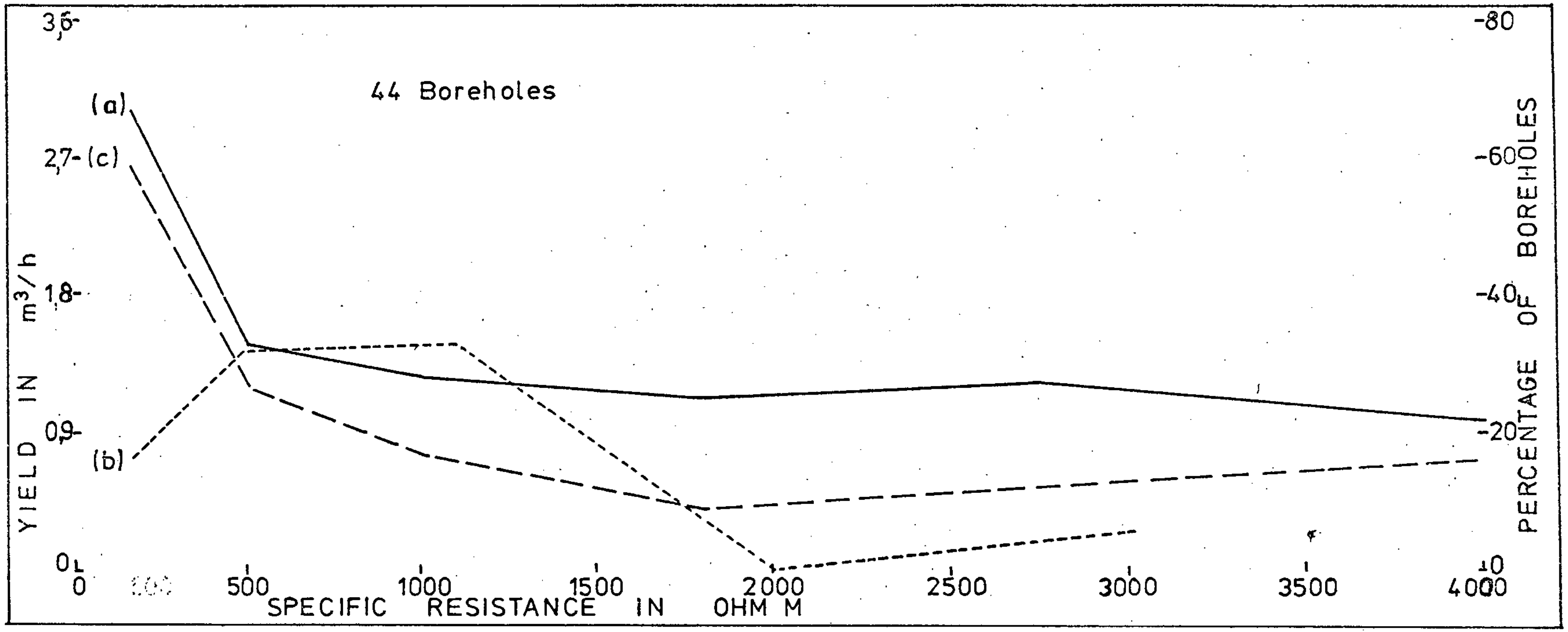


FIG.48 - GRAPHS OF SPECIFIC RESISTANCE AT THE GROUNDWATER REST LEVEL (AS DEDUCED FROM BOREHOLE LOGGING) AS A FUNCTION OF:
(a) THE PERCENTAGE OF SUCCESSFUL BOREHOLES;
(b) THE PERCENTAGE OF BOREHOLES YIELDING 1,37 m^3/h OR MORE;
(c) THE AVERAGE YIELD OF THE BOREHOLES;
ARCHAEAN GRANITE, N.W.TRANSVAAL.

section 8.1.3.1, although the optimum apparent specific resistance is not so well-defined in the latter. It must be emphasised that the resistivities measured by borehole logging were the actual specific resistances of the rock and interstitial water at the depths at which water was struck; whereas the apparent resistivity measured from the surface was the sum of the resistivities of all the layers from the surface down to the depth at which water was struck. The agreement in the results obtained by the two methods of measuring is, therefore, very good.

If only economic supplies of 1,37 m^3/h or more are taken into account, only ten boreholes (22,7 per cent) were of economic importance; and the highest percentage of successful boreholes was between 400 and 1 400 ohm m (Fig. 48(b)).

8.1.3.3 ELECTRO-MAGNETIC METHODS

A total of 27 set-ups were surveyed on thirteen farms with the circular method developed by Enslin (1955). Because the instrument used was not adapted to measure structures under a thick cover of soil or alluvium, as discussed in chapter 5.2.2.1.4, the results were disappointing on a number of farms. On five farms (on which nearly half of the number of set-ups were surveyed) no anomalies could be found, although the set-ups were sited to intersect the possible extensions of structures on neighbouring farms. On several other farms weak and ill-defined anomalies which could not be traced for long distances along strike, were found. These anomalies could have been due to surface irregularities and not deep structures. On the farms Houtkraal (Portion of Blinkwater 628), Krugerspan 804, Franksvley 807, Blinkwater Road Camp, Klipdrift 842 and Laastepoort 840 relatively strong and well-defined anomalies were found. In all of these cases the anomalies were between 20 and 25 m from boreholes which yielded good supplies of water. Only in the case of the Blinkwater Road Camp could the anomaly be correlated positively with the strike and position of the structure which yielded a strong supply of ground-water.

At this stage and with this type of instrument, the electro-magnetic method did not yield results which could be used for the selection of borehole sites, and no further use was made of this instrument. With the linear method of lay-out, which is much quicker, much more information about the occurrence of structures and the presence of economic reservoirs of ground-water should be obtainable; especially if used in conjunction with other geophysical methods. The instrument used should have a greater effective depth of penetration.

8.1.4 ANALYSES OF SURFACE FEATURES

By using geophysical methods only, no optimum methods for locating economic supplies of ground-water could be determined. Other parameters were therefore investigated.

8.1.4.1 TOPOGRAPHY

The area in which the granite is found has a relatively low summer rainfall with a pronounced January maximum, when evapo-transpiration is very high. Abnormally high rainfall very seldom occurs, the average deviation from normal being less than 20 per cent (Climate of South Africa, 1960). It could, therefore, be deduced that very little water infiltrates to replenish the ground-water reservoir on the featureless forested plains, except where the water is collected in pans or dams, or moved slowly along the large laagtes and rivers. Information about the positions of boreholes relative to such surface features was examined for 220 boreholes, of which reliable information could be collected. The results are shown as a histogram in Fig. 49(a). The following conclusions can be drawn:

(i) Forty-one per cent of the boreholes were drilled within 100 m of rivers or their large tributaries, and 58 per cent of these boreholes were successful.

(ii) Nearly 19 per cent were drilled within 100 m of small pans with a restricted catchment area. Forty-nine per cent of these boreholes were successful, which is still appreciably higher than the average for the area.

(iii) The remaining 40 per cent of the boreholes were drilled on flat featureless surfaces with no visible topographic relief. Only 22,5 per cent of these boreholes were successful.

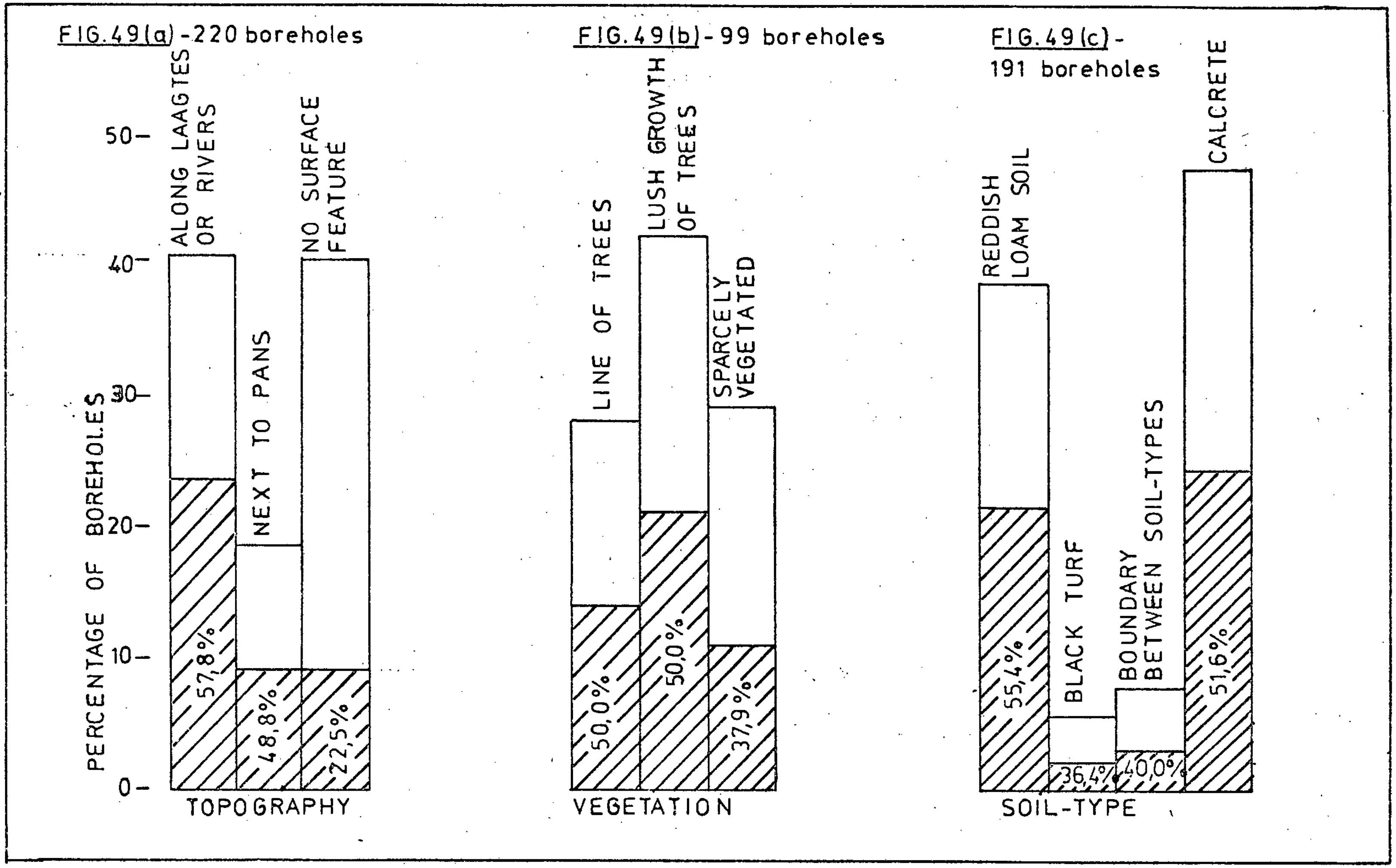


FIG.49 - HISTOGRAMS OF THE PERCENTAGE OF SUCCESSFUL BOREHOLES RELATIVE TO (a) TOPOGRAPHICAL FEATURES; (b) VEGETATION; (c) SOIL-TYPE; ARCHAEAN GRANITE N.W.TRANSVAAL. (Successful boreholes shaded).

8.1.4.2 VEGETATION

Vegetation could not be positively correlated with the geology, but from air photos and inspection in the field, it was possible to distinguish between dense growth, lines of trees, and thinly vegetated areas. The result of the grouping of 99 boreholes according to these parameters, is shown as a histogram in Fig. 49(b). Nearly 71 per cent of the boreholes were drilled where there was dense growth or a line of trees, with 50 per cent of success. This was higher than the percentage of successful boreholes in thinly-covered areas, but the difference was not well-defined, and could not be used positively as a criterion for the selection of successful borehole sites.

8.1.4.3 SURFACE COVERING

The permeability of the surface covering should have an important influence on the replenishment of ground-water. In this area four types of surface cover were investigated:

(i) Black turf along drainage lines, which always had low permeability.

(ii) The contact zone between black turf and sandy loam at the edges of drainage lines, usually with good permeability.

(iii) Reddish sandy loam to light-coloured sand or sandy soil, which had medium to high permeability.

(iv) Surface limestone of at least three metres in thickness, sometimes with a cover of up to one metre of soil or sand, with high permeability.

The results of 191 boreholes are given in Fig. 49(c) as a histogram. Unfortunately only 6 per cent and 8 per cent of the boreholes were drilled in surface covering of classes (i) and (ii), and in classes (iii) and (iv) the percentages of successful boreholes were nearly similar. It can therefore be concluded that the type of surface covering in the immediate vicinity of the borehole, plays a minor role in its yield.

It is possible that more information collected over a longer period might yield more positive results, especially with regard to replenishment of the ground-water and the safe yield of boreholes. Another reason for this result may be due to the movement of ground-water along cracks and joints. The ground-water reservoir may be far removed from the area of infiltration, and therefore, from the type of soil where it infiltrated.

8.1.5 THE EFFECT OF DYKES

No outcrops of dykes were seen, except along the Marico River. Due to the thick cover of soil, sand or calcrete, it was difficult to determine the boundaries of dykes accurately by geophysical investigations. In most cases borehole records were not accurate enough to decide whether the dyke-rock was struck above or below the ground-water rest level.

After geophysical surveys, photo-geological mapping, and the screening of borehole logs, evidence was found of 48 boreholes which were drilled within 30 m of a dyke in the granite. Only a small percentage were drilled in or near a major drainage line. The results were as follows:

(i) Twenty boreholes drilled on the dykes struck solid rock above the ground-water rest level and all were failures.

(ii) Twenty eight boreholes were drilled next to or near to the contacts of dykes with the granite and fifty per cent were successful. According to resistivity depth probes the depth of weathering was favourable for striking ground-water in twelve of the boreholes investigated. Eight of these boreholes (67 per cent) were successful.

8.1.6 CONCLUSIONS

At this stage it is not possible to determine optimum conditions for finding economic supplies of ground-water in the granite in the North-western Transvaal. However, the probability of drilling a successful borehole is better than average if the following conditions are complied with when selecting a site:

(i) The specific resistance as determined by surface resistivity surveys must be less than 150 ohm m at a depth which is equal to or greater than the ground-water rest level.

(ii) The borehole must be sited near a river or one of its major tributaries, or where impounded water can infiltrate to augment the ground-water supply.

(iii) Boreholes sited near to the contact of a dyke in weathered granite as traced by geophysical measurements, have a better than average probability of yielding an economic supply.

(iv) More than half of the boreholes yield water in joints and cracks below the depth of weathering. Boreholes should therefore, be drilled to depths of 20 to 30 m deeper than the depth of weathering.

(v) The depths at which water was struck in 93,5 per cent of the successful boreholes, were shallower than 76 m. Boreholes should, therefore, be drilled to depths of approximately 80 m to ensure that the maximum yield is struck. This depth is qualified by condition (iv).

8.2 CAPE PROVINCE

8.2.1 OCCURRENCE

Most of the granite and gneiss in this area have an isotopic age of approximately 1 050 million years, which is the age of the last major orogeny according to Nicolaysen and Burger (1965). The name Grey Gneiss, which was suggested by Von Backström (1964) is used for these rocks, which probably consist predominantly of metamorphosed sediments of the Kheis System and injected magmatic material. The Namaqualand Granite-gneiss, which is described by other authors, also consists of granitised and mobilised sediments and magmatic material, and is grouped with the Grey Gneiss. The Geelbeksdam Granite, with an isotopic age of between 2 477 and 2 710 million years, is intrusive into the Marydale Series of the Kheis System and the Soetlief Formation. It was not affected by the later orogenic deformation.

The hydrological properties of all of these granites and gneisses are very similar. The Grey Gneiss is treated as a unit, and discussed in this chapter with regard to climatic conditions and surface cover, and not with regard to isotopic age or origin.

8.2.1.1 DISTRIBUTION

The granite and gneiss are found throughout the area, from west of the Kamiesberge to east of Prieska; and from north of Upington and the Richtersveld to south of Nuwerus and Bitterfontein. It is bordered on the east and north-east by rocks of the Kheis and Transvaal Systems, and on the north by the Nama System, the Karoo System, and the Orange River. On its western border it is covered by Recent deposits, and on the south and south-east by the Nama System and the Dwyka Series of the Karoo System. Remnants of the Kheis System form extensive inliers in the granite and gneiss, and outliers of the Nama and Karoo Systems cover the granite and gneiss, usually in isolated areas.

The Geelbeksdam Granite abuts against the Doornberg Fault on the east, and its western and southern boundaries are sediments and granitised sediments of the Kheis System. To the north it is intruded into the Soetlief lavas and covered by younger formations.

The rainfall over this large area varies between an average of 53 mm per year and 343 mm per year. It is proposed to discuss the occurrence of ground-water in the granite and gneiss with relation to rainfall districts based on the average annual rainfall; and where the granite and gneiss are covered by younger formations, on the type of covering.

8.2.1.2 TOPOGRAPHY AND LITHOLOGY

Most of the granite and gneiss is found on the Bushmanland Plateau, where hardly any topographical features are seen. This plateau includes the "Kaiingbulte" to the east and south-east of Kenhardt. The Namaqua Highlands, with the Kamiesberge as its major present feature, is built by the Namaqualand Granite-gneiss. In this area, and in the broken country to the west and north as far as the Orange River, these rocks form large rounded domes rising from the sand and alluvium-filled valleys. The Inselberge of the area between Springbok and Kakamas consist principally of granite and gneiss, sometimes with a capping of Kheis quartzite. The mountainland between Springbok and the Richtersveld is formed by Namaqualand Granite-gneiss and quartzite of the Nama System. South of Garies the topographic relief due to the granite and gneiss becomes more subdued. From Kakamas to the north and east the prominent ridges and mountains are built from sediments of the Kheis System, and the Grey Gneiss occupies the valleys in between. The Geelbeksdam Granite also occupies low-lying areas without prominent relief. Over the whole area the Grey Gneiss is more often found in areas without prominent relief than in mountainous regions like the Kamiesberge and the Richtersveld.

Lithologically there is a great variety of tonalitic, granitic, granodioritic, migmatic and hybrid varieties of generally gneissic rocks. The Geelbeksdam Granite is usually leucocratic and coarse-grained, but may be reddish, or darker-coloured and gneissic due to layers with varying amounts of mica. Very few xenoliths were seen.

The Grey Gneiss is usually melanocratic, often a biotite gneiss, and the texture may vary over very short distances between porphyroblastic and coarse-grained to fine-grained. Xenoliths are numerous in places, and the gneiss is often garnetiferous. The coarse-grained variety is usually a granite without any foliation or lineation, while the fine-grained type may be strongly foliated and lineated. In the latter type xenoliths are usually totally absent. Flow structures are prominent, and it is found as lit-par-lit intrusions in the Kheis System. The present author described it in the eastern part of Geological Sheet 2821A as "a rock-type of granitic or gneissic structure varying between a granodiorite, a biotite granite, and a hornblende granite". (Schumann, 1963)

8.2.2 OCCURRENCE OF GROUND-WATER

8.2.2.1 GEELBEKSDAM GRANITE

The results of 73 boreholes drilled in this formation were analysed. From the cumulative graph of yield against percentage of total number of boreholes (Fig. 50) can be seen that 41,1 per cent of the boreholes were failures, yielding less than 0,45 m^3/h. A high percentage of the boreholes, viz. 20,5 per cent (34,9 per cent of the successful boreholes) yielded 4,54 m^3/h or more. This is a very high percentage of strong boreholes for granite or gneiss in the North-western Cape Province.

The depths at which water was struck in 59 boreholes and in 49 successful boreholes are shown in the form of histograms in Fig. 51. In 94,9 per cent of all boreholes and 93,9 per cent of successful boreholes water was struck shallower than 60 m. In more than 66 per cent of all boreholes and 69 per cent of successful boreholes water was struck before a depth of 30 m was reached.

The rest levels in 51 boreholes are shown as a histogram in Fig. 52. In 55 per cent of the boreholes it is shallower than 15 m and in 92 per cent shallower than 45 m.

Electrical resistivity depth probes were done at 24 of these boreholes (Fig. 53). In nineteen of them the specific resistances at the depth of the rest level were 260 ohm m or less. The percentage of successful boreholes was 84,2, and the average yield

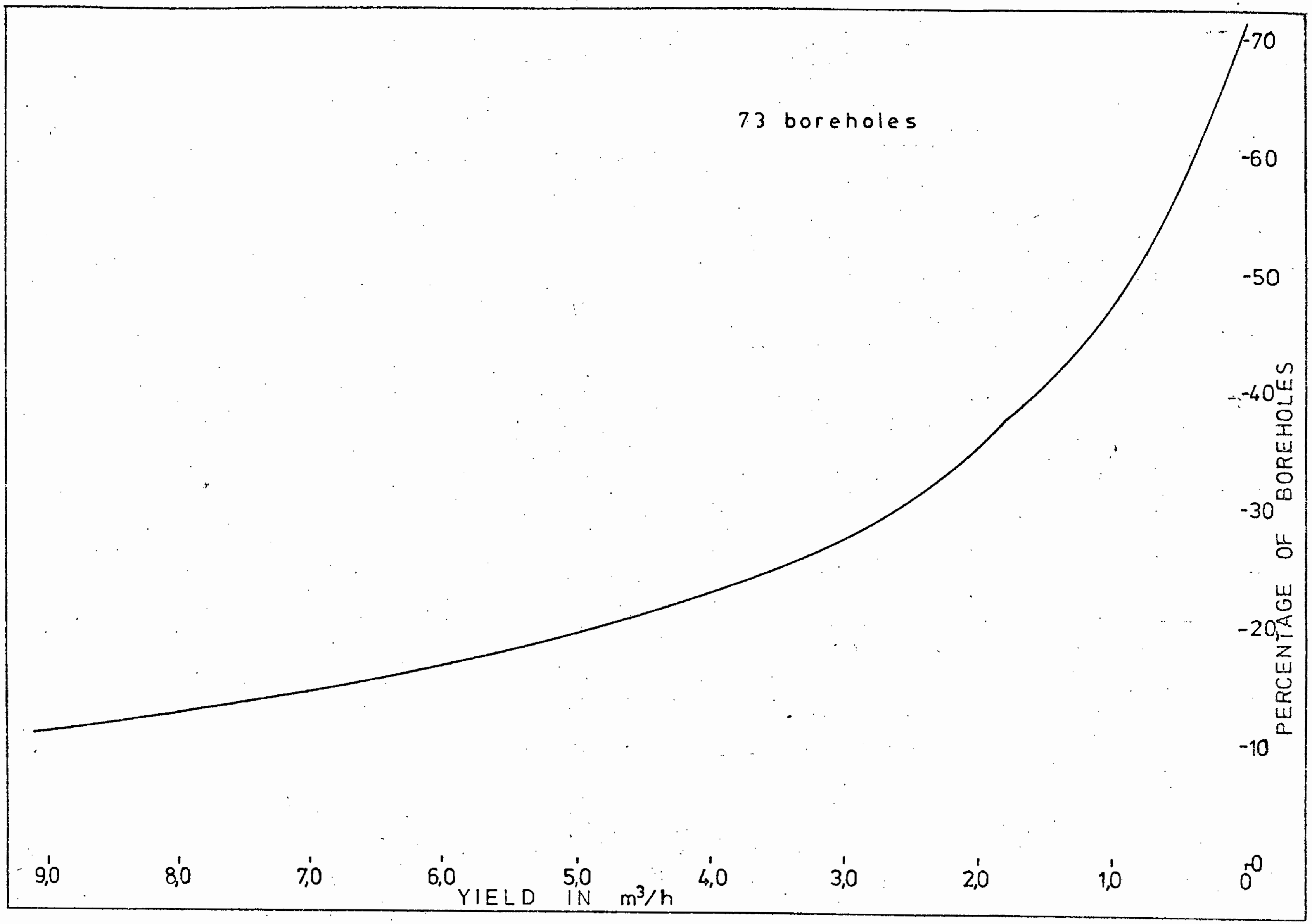


FIG. 50 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF BOREHOLES, GEELBEKSDAM GRANITE, N.W.CAPE PROVINCE.

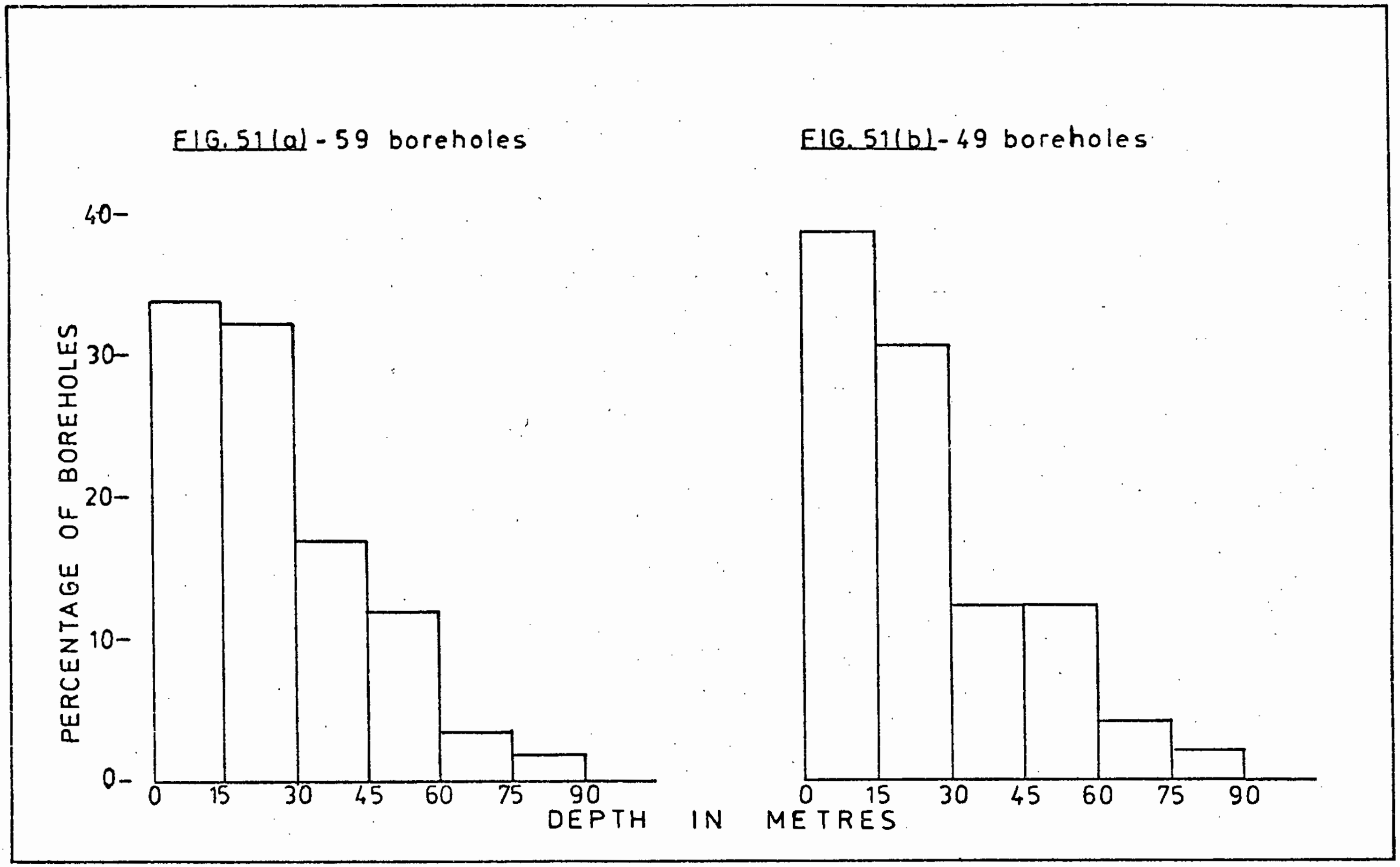


FIG. 51 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF (a) THE TOTAL NUMBER OF BOREHOLES; (b) THE SUCCESSFUL BOREHOLES; GEELBEKSDAM GRANITE, N.W. CAPE PROVINCE.

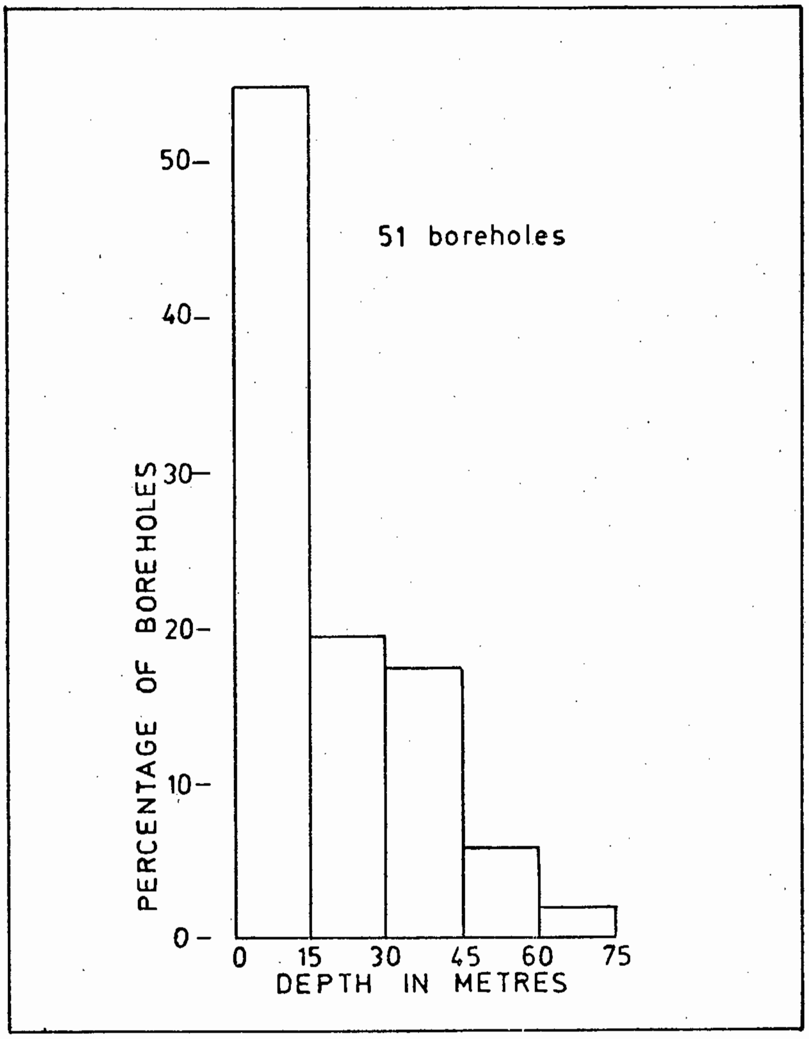


FIG.52 - HISTOGRAM OF REST LEVELS AS PERCENTAGE OF THE NUMBER OF BOREHOLES; GEELBEKSDAM GRANITE, N.W.CAPE PROVINCE.

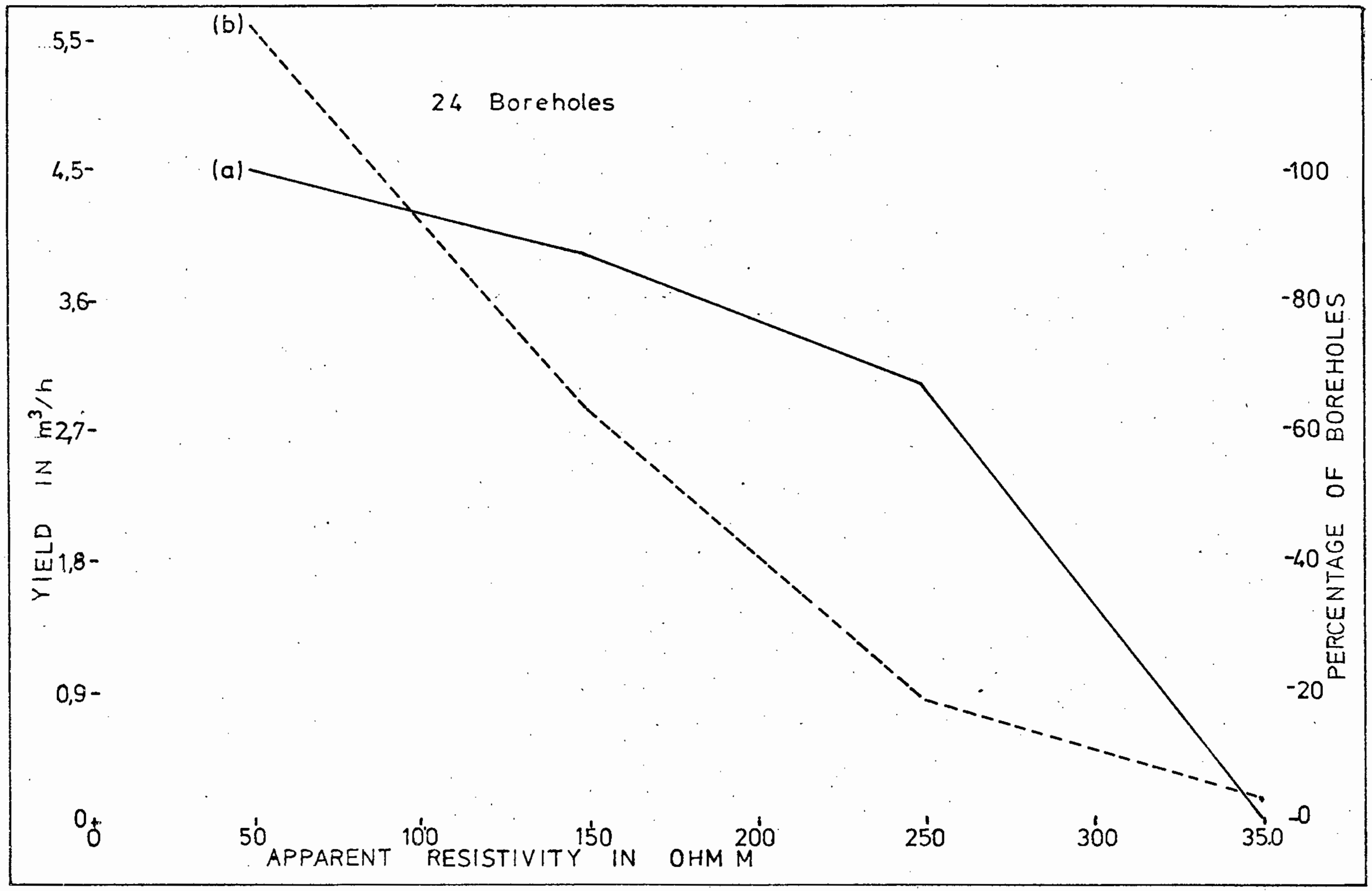


FIG. 53 - GRAPHS OF APPARENT RESISTIVITY AT THE GROUNDWATER REST LEVEL AS A FUNCTION OF (a) THE PERCENTAGE OF SUCCESSFUL BOREHOLES; (b) THE AVERAGE YIELD OF BOREHOLES; GEELBEKSDAM GRANITE, N.W. CAPE PROVINCE.

3,2 m^3/h. Of the five boreholes with higher resistivities, only one yielded 0,45 m^3/h, and the others were failures. Of the fourteen boreholes with specific resistances of 200 ohm m or less, only one was a failure (92,8 per cent of successful boreholes), and the average yield was 4,03 m^3/h.

It can, therefore, be concluded that the Geelbeksdam Granite is a relatively good aquifer, probably for the following reasons:

(i) It is found west of the Doornberge and occupies the low-lying portions of an area with an average annual rainfall of 200 mm. Major tributaries of the Orange River cross this area.

(ii) It is a coarse-grained quartzitic granite, weathering to a coarse sand with high permeability. Where there is a surface covering it usually consists of calcrete, which also has a high permeability.

(iii) The depth of weathering in the granite is deeper than the ground-water rest level in most of the boreholes. The rest level is shallower than in most of the other formations in the North-western Cape Province.

8.2.2.2 GREY GNEISS

A very large number of boreholes have been drilled in the granitic rocks which are grouped under the name of Grey Gneiss. This mass of data in a formation which can be considered to be hydrologically homogeneous, made it possible to investigate the effect of the difference in average annual rainfall on the yield of boreholes. The 2 314 boreholes investigated were divided into four groups:

Boreholes in areas with an average annual rainfall of

(a) Less than 100 mm;

(b) Between 100 and 150 mm;

(c) Between 150 and 200 mm;

(d) More than 200 mm.

Unfortunately the results of only 40 boreholes in the last group could be traced, so that a full analysis was not possible.

In Fig. 54(a) histograms of the percentages of successful boreholes in relation to the average annual rainfall are shown. The percentages increase with increasing rainfall, a major step occurring between the groups with average annual rainfall of 100-150 mm, and 150-200 mm.

The same effect is seen in Fig. 54(b), for yields of more than 4,55 m^3/h. In this case the differences are even greater than in Fig. 54(a). Because most of these boreholes are situated on the Bushmanland Plateau, topographical differences are negligible. The major difference between the groups seems to be the average annual rainfall, and as a consequence, the intensity of the summer rainfall.

8.2.2.3 GREY GNEISS WITH AVERAGE ANNUAL RAINFALL OF LESS THAN 100 MM

The area in which the average annual rainfall is less than 100 mm

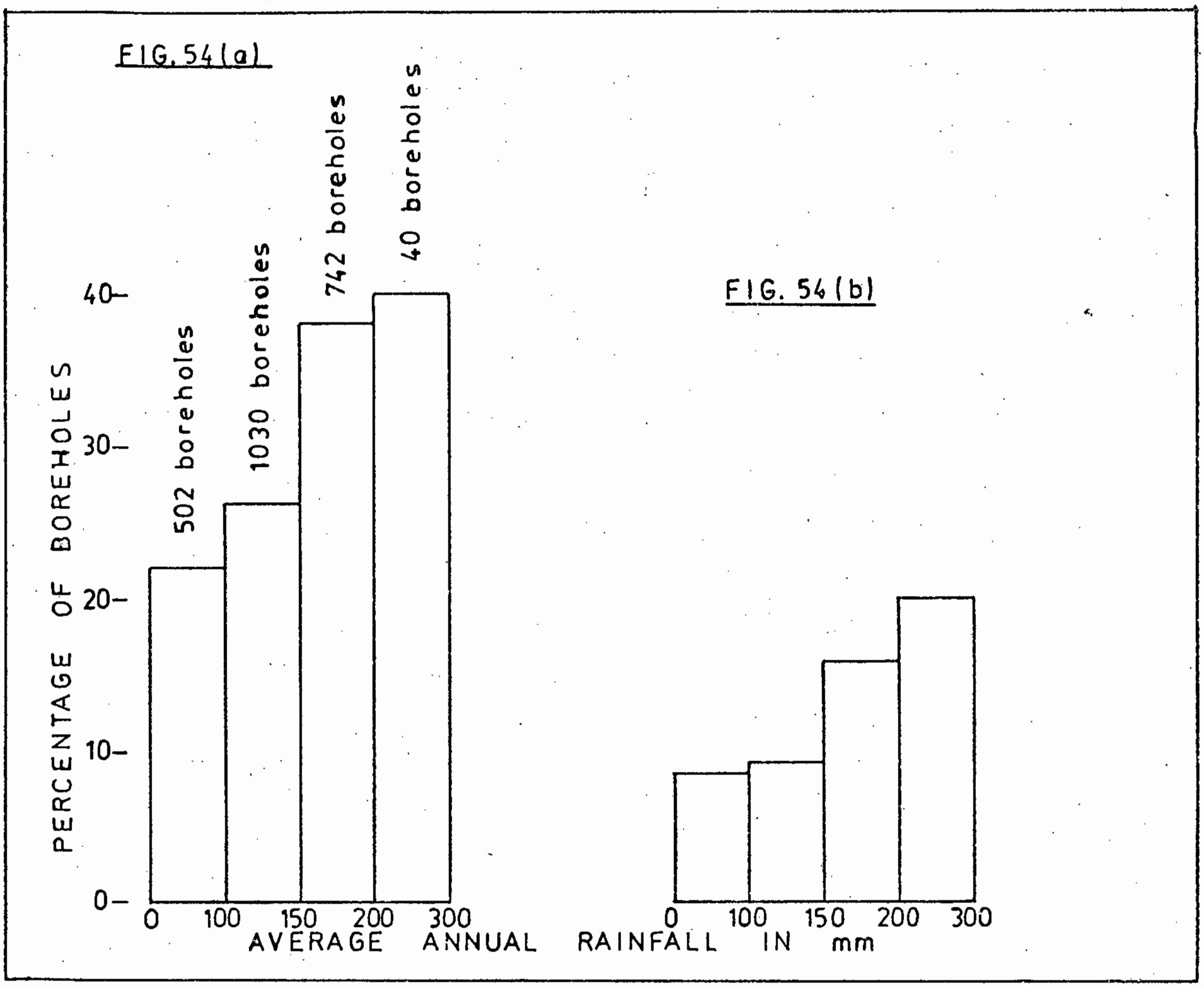


FIG. 54 - HISTOGRAMS OF THE RELATION BETWEEN THE AVERAGE ANNUAL RAINFALL AND (a) THE PERCENTAGE OF SUCCESSFUL BOREHOLES; (b) THE PERCENTAGE OF BOREHOLES YIELDING 4,5 m^3/h OR MORE; GREY GNEISS, N.W. CAPE PROVINCE.

forms a broad belt from the Orange River between Henkries and Onseepkans in the north-west, to the south-east between Brandvlei and Loeriesfontein. Over the greater part of this area the veld type is Arid Karoo. Topographically it forms a portion of the Bushmanland Plateau, with some broken veld near the Orange River.

Results of 502 boreholes drilled in this area in the granitic rocks were analysed. The cumulative graph (Fig. 55(a)) shows that 77,9 per cent of these boreholes yielded less than 0,45 m^3/h, and 55,8 per cent were totally dry. Only 4,3 per cent yielded more than 4,55 m^3/h.

In the greatest percentage of boreholes water was struck between depths of 30 to 45 m (Fig. 56(a)). Between 30 and 90 m, 66 per cent of all the boreholes, and 69,6 per cent of the successful boreholes, yielded water (Fig. 57(a)). A cumulative graph was drawn of the depth at which water was struck relative to the percentage of boreholes (Fig. 58(a)(i)). In 49 per cent of the boreholes water was struck shallower than 60 m, in 77 per cent shallower than 90 m, and in 92,5 per cent shallower than 120 m. In the case of successful boreholes the respective percentages for the same depth intervals were 53 per cent, 80 per cent, and 92,5 per cent. The difference can be explained by the fact that water was struck more easily and at a shallower depth in the better weathering and jointing of

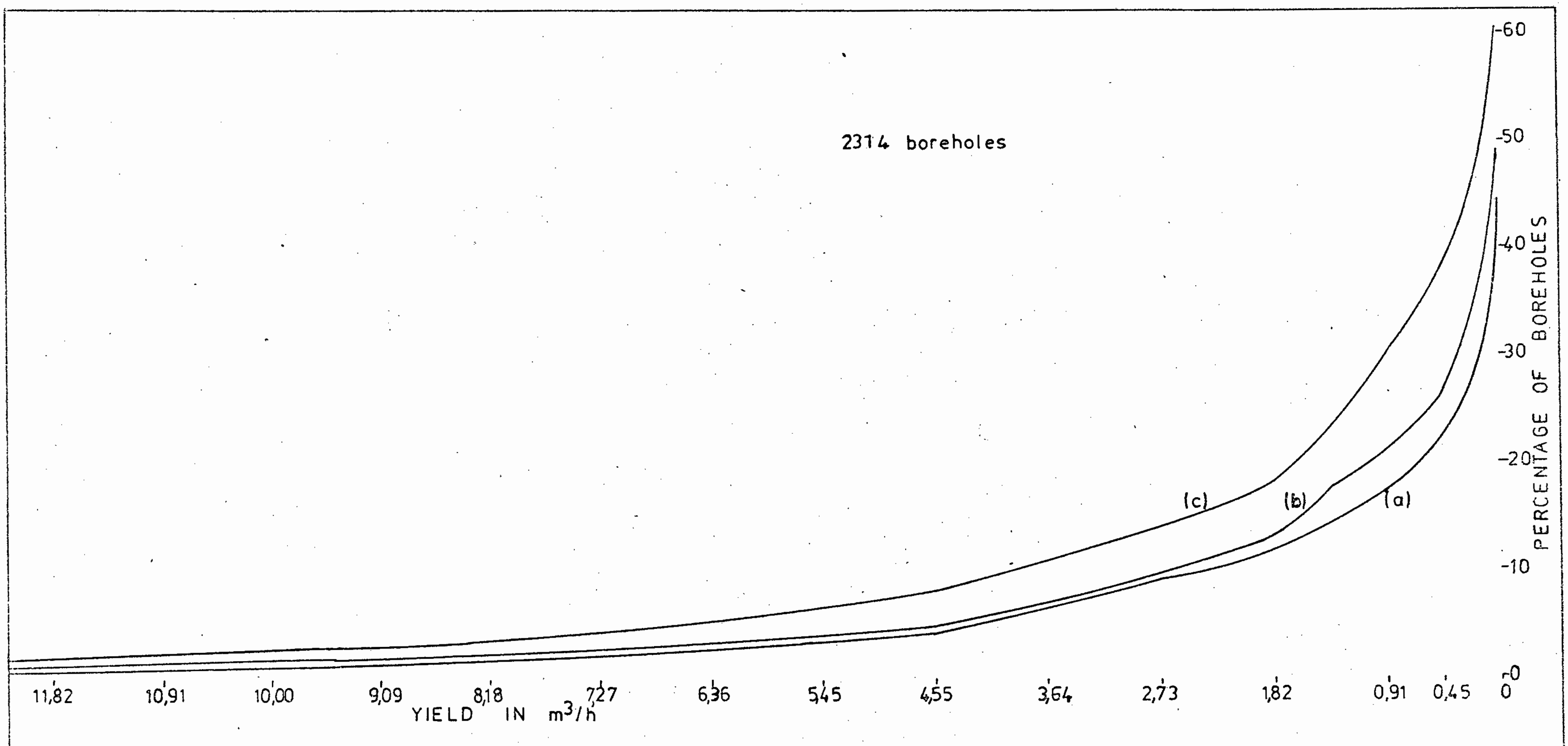


FIG.55 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF TOTAL NUMBER OF BOREHOLES FOR AVERAGE ANNUAL RAINFALL OF (a) 0-100 mm; (b) 100-150 mm; (c) 150-200 mm; GREY GNEISS, N.W.CAPE PROVINCE.

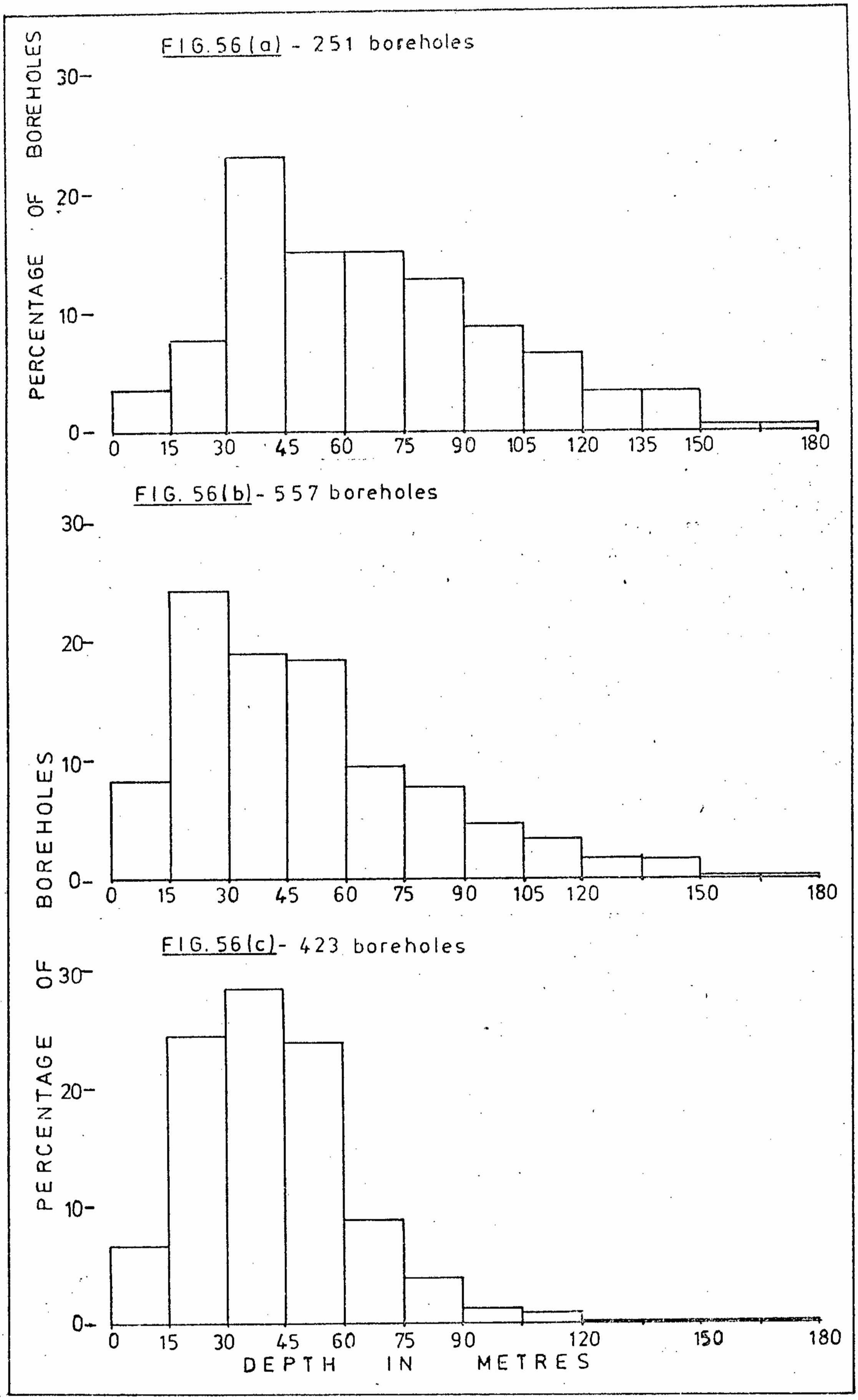


FIG. 56 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE TOTAL NUMBER OF BOREHOLES, WITH AVERAGE ANNUAL RAINFALL OF (a) 0-100 mm; (b) 100-150 mm: (c) 150-200 mm; GREY GNEISS, N.W. CAPE PROVINCE.

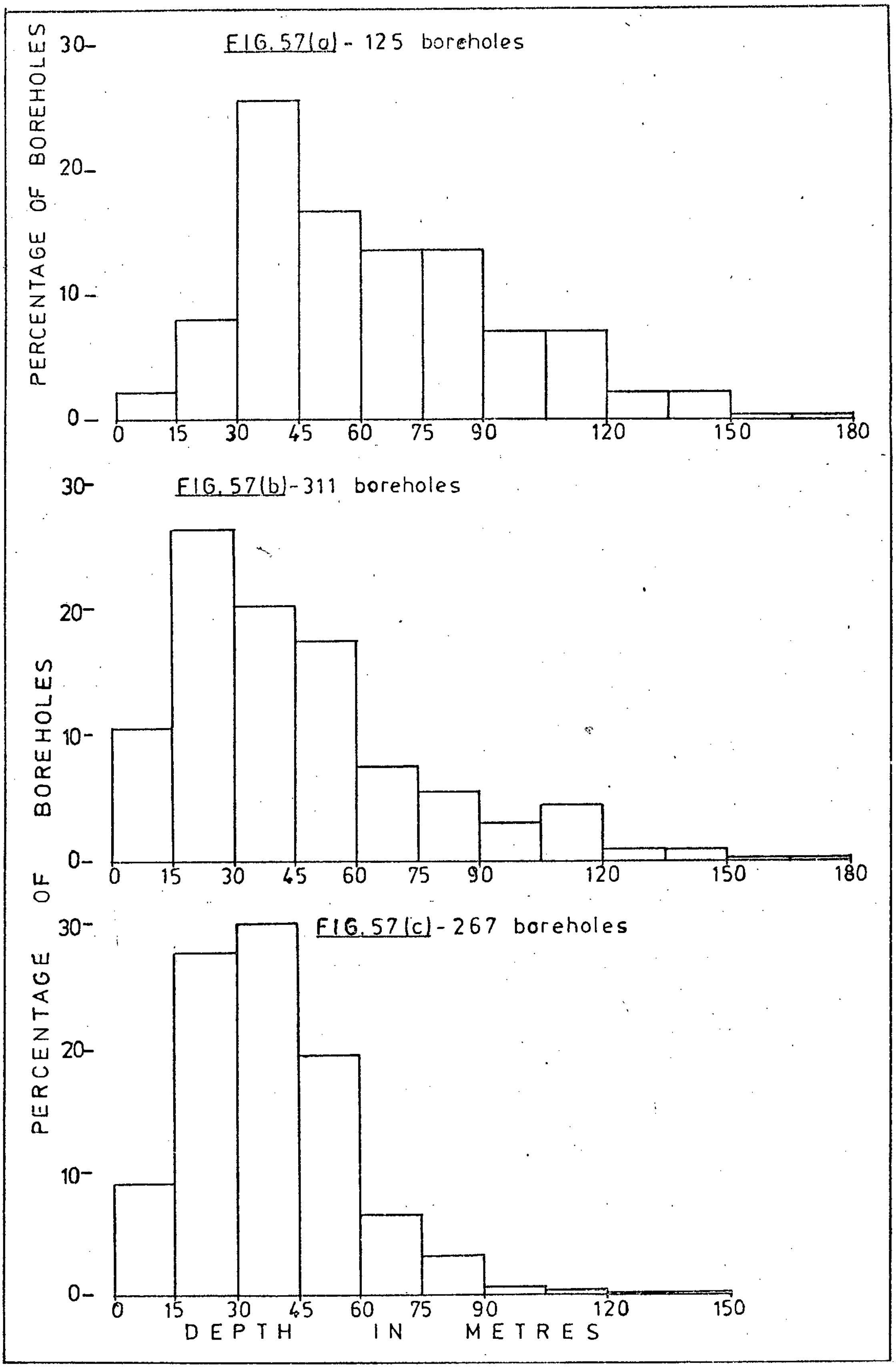


FIG. 57 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE NUMBER OF SUCCESSFUL BOREHOLES, WITH AVERAGE ANNUAL RAINFALL OF (a) 0-100 mm; (b) 100-150 mm; (c) 150-200 mm; GREY GNEISS, N.W. CAPE PROVINCE.

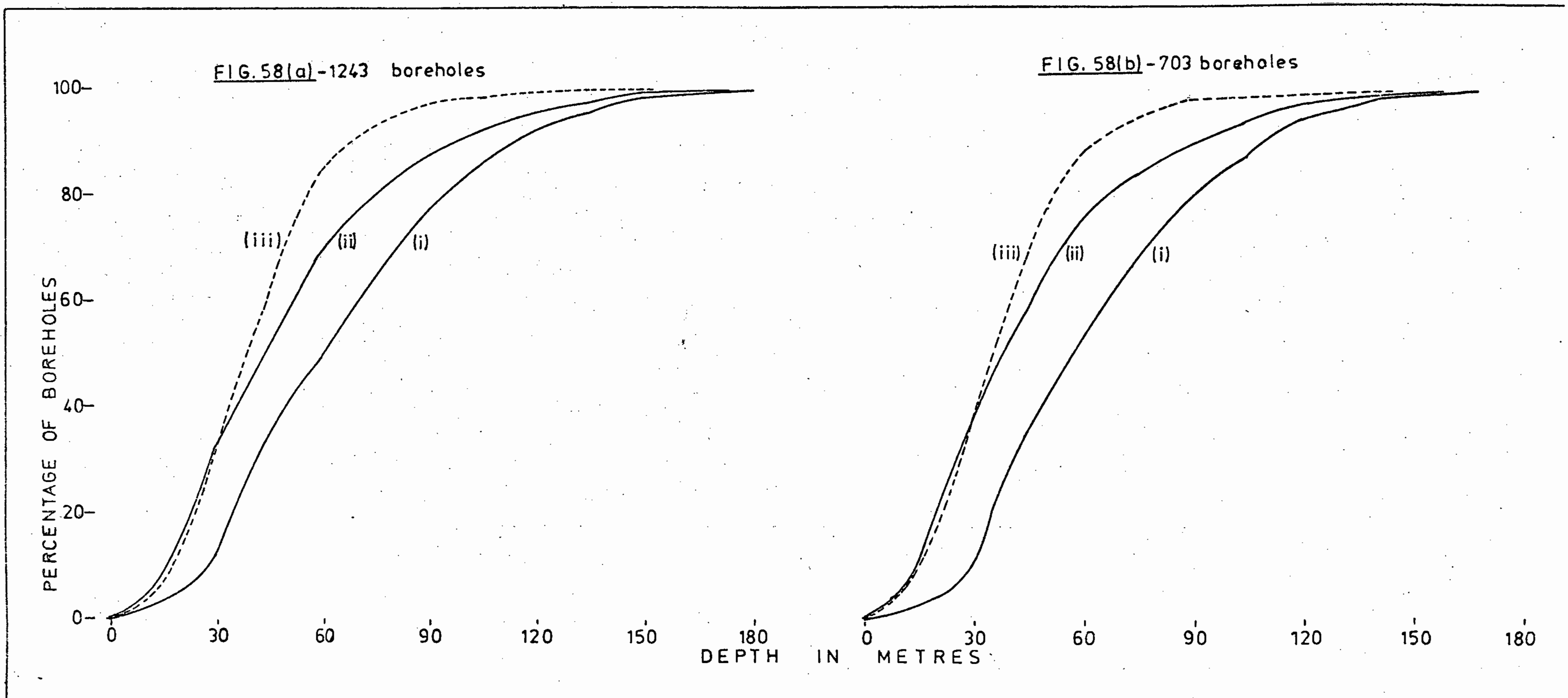


FIG. 58 - CUMULATIVE GRAPHS OF DEPTH AT WHICH WATER WAS STRUCK AS A FUNCTION OF THE PERCENTAGE OF THE (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; WITH AVERAGE ANNUAL RAINFALL OF (i) 0-100 mm; (ii) 100-150 mm; (iii) 150-200 mm; GREY GNEISS, N.W. CAPE PROVINCE.

the higher-yielding aquifers. The same tendency is evident from the cumulative graphs of the rest levels (Fig. 59(a)(i) and Fig. 59(b)(i)). In 84,6 per cent of the boreholes the rest levels were shallower than 76 m, increasing to 88,9 per cent for the successful boreholes.

Due to the aridity of the area and the consequent restricted recharge, there is very little confining pressure in the boreholes. In more than 50 per cent of the boreholes (Fig. 60(a)(i)) water was struck less than 12 m below the rest level, and in more than 70 per cent, less than 24 m below this level. On the other hand water was struck in nearly 23 per cent of the boreholes between 30 and 120 m below the rest level. These boreholes yielded water in joints and cracks well below the depth of weathering, after solid rock had been traversed. The figures for the same depth intervals for successful borehols were practically the same (Fig. 60(b)(i)).

In 267 boreholes the depth at which water was struck could be calculated relative to the depth of weathering. The results are shown in the histogram of Fig. 61(a). In 15,7 per cent of the boreholes water was struck between 1 and 6 m shallower than the depth of weathering, and in 41,8 per cent between 12 m shallower and 18 m deeper than the depth of weathering. In a total of 67,1 per cent of the boreholes water was struck in cracks and joints below the depth of weathering; 15,7 per cent exceeding

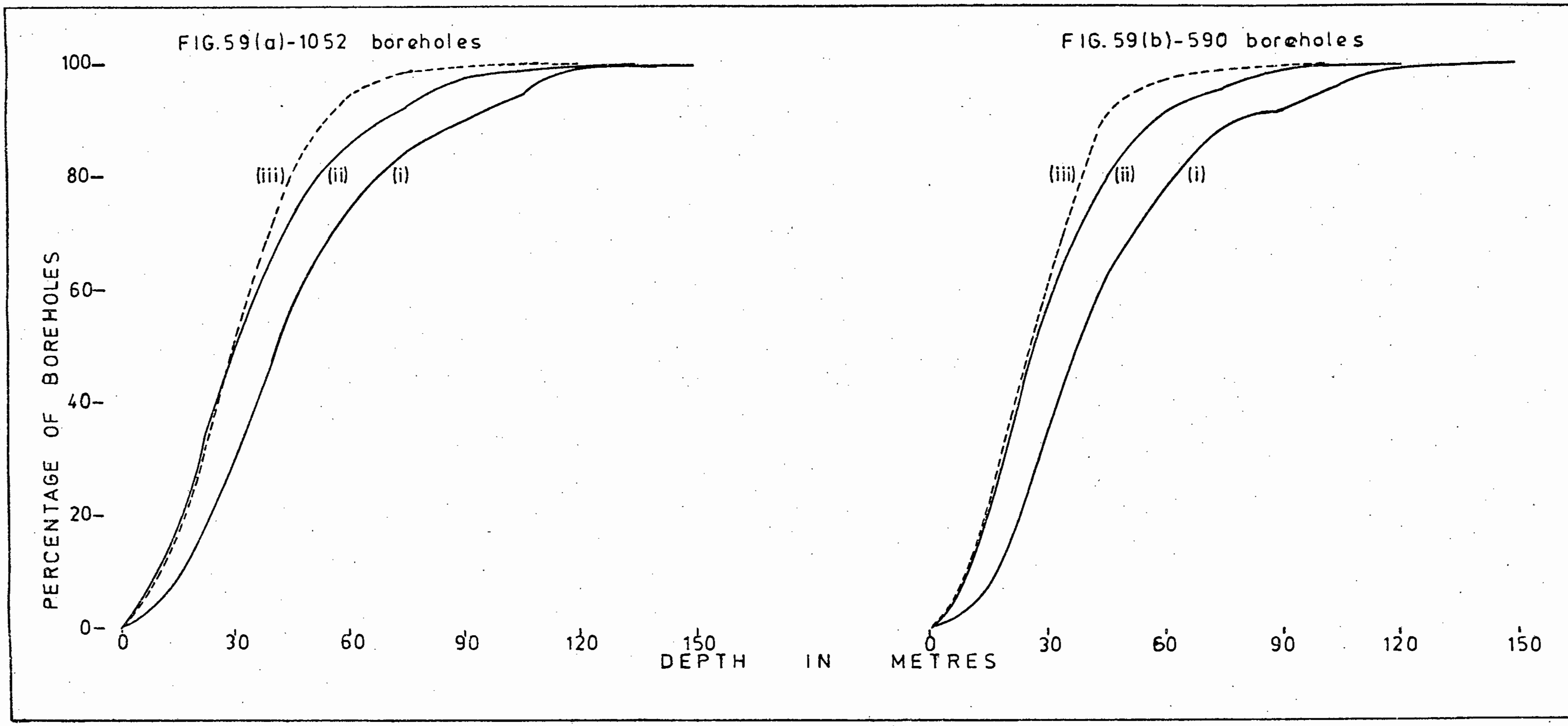


FIG.59 - CUMULATIVE GRAPHS OF GROUNDWATER REST LEVELS AS A FUNCTION OF THE PERCENTAGE OF THE (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; WITH AVERAGE ANNUAL RAINFALL OF (i) 0-100 mm; (ii) 100-150 mm; (iii) 150-200 mm; GREY GNEISS, N.W. CAPE PROVINCE.

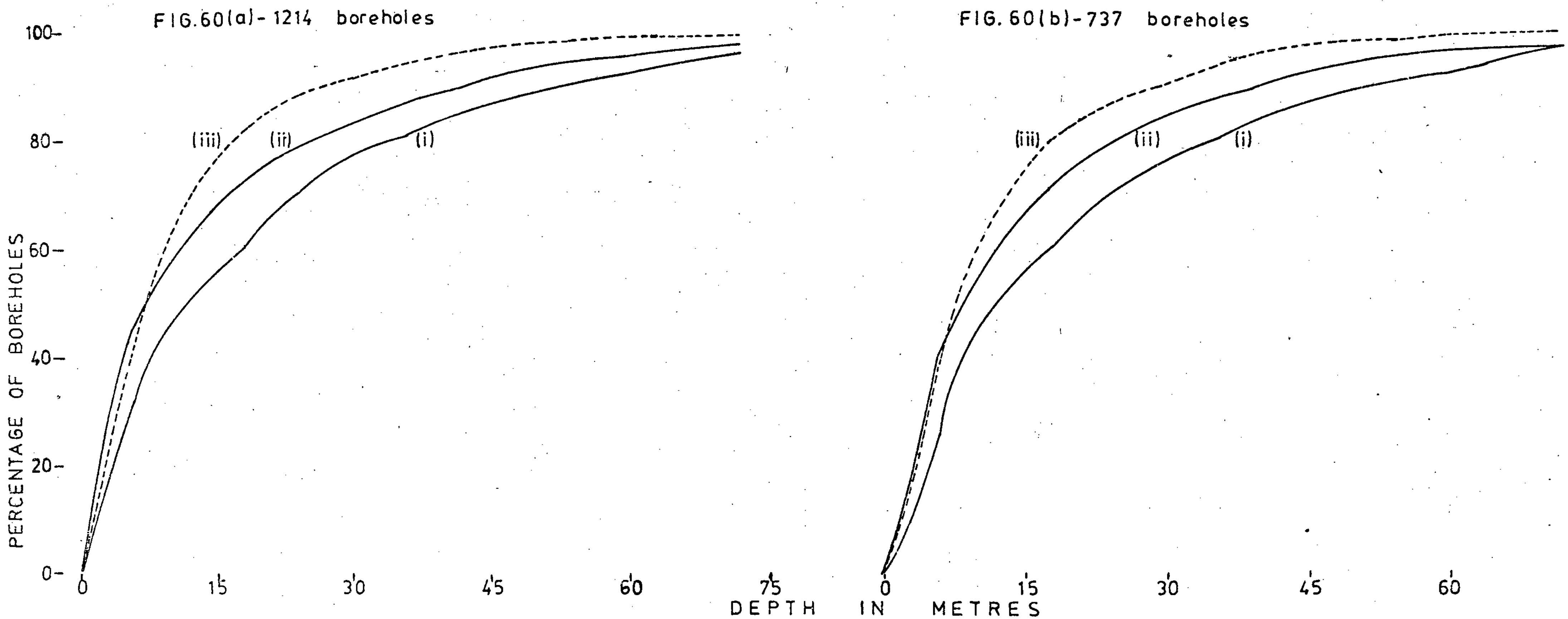


FIG.60 - CUMULATIVE GRAPH OF DEPTH BELOW REST LEVEL AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF THE (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; WITH AVERAGE ANNUAL RAINFALL OF (i) 0-100 mm; (ii) 100-150 mm; (iii) 150-200 mm; GREY GNEISS N.W.CAPE PROVINCE

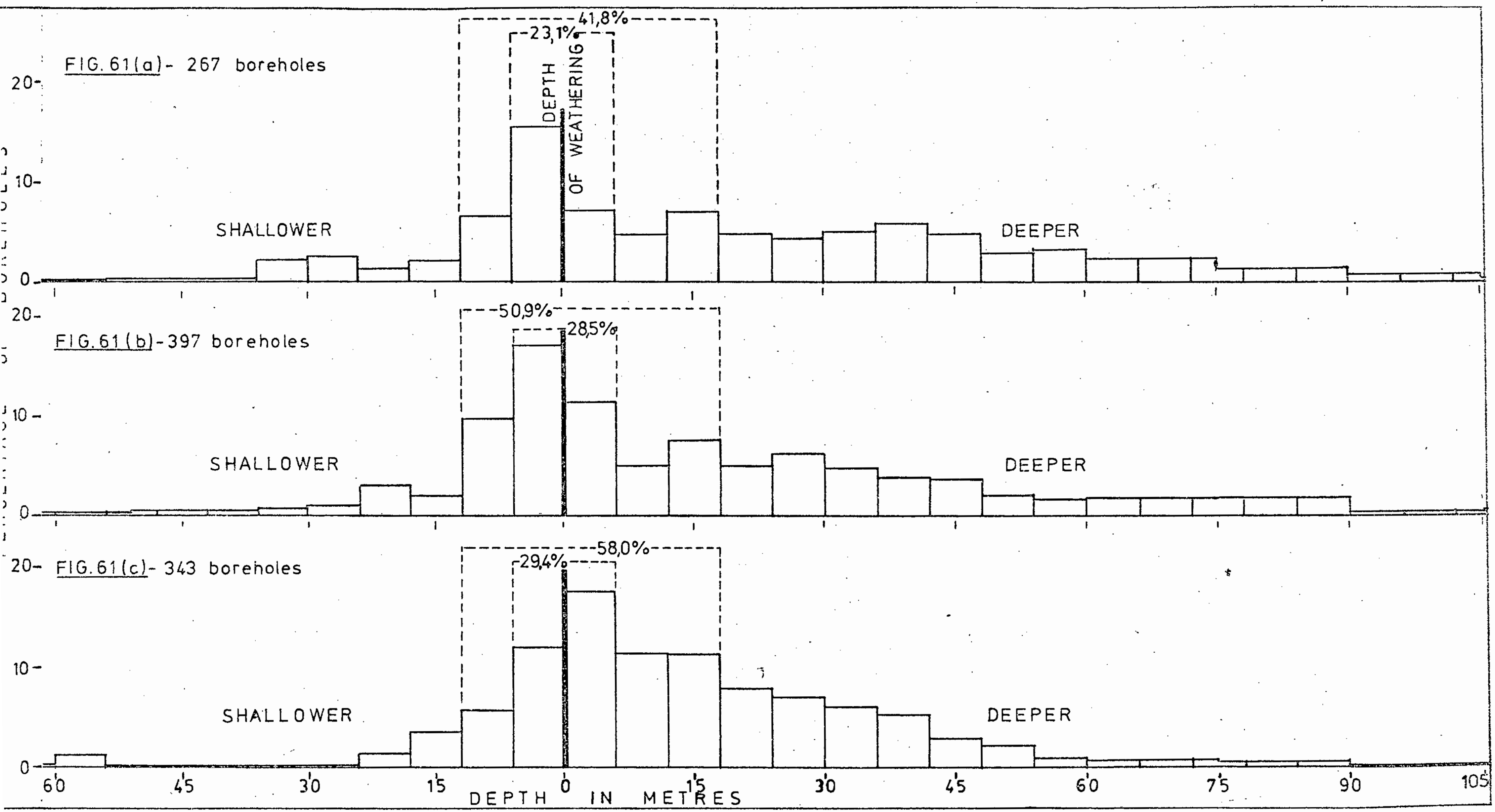


FIG. 61 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK IN ALL BOREHOLES RELATIVE TO THE DEPTH OF WEATHERING; WITH AVERAGE ANNUAL RAINFALL OF (a) 0-100 mm; (b) 100-150 mm; (c) 150-200 mm; GREY GNEISS, N.W. CAPE PROVINCE.

61 m, and six per cent 91 m. As could be expected, more successful boreholes yielded water shallower than the depth of weathering, viz. 39 per cent. In 50,3 per cent of successful boreholes water was struck between 12 m shallower and 18 m deeper than the depth of weathering.

8.2.2.4 GREY GNEISS WITH AVERAGE ANNUAL RAINFALL OF 100 TO 150 MM

The areas in which the average annual rainfall is between the above limits lie on the south-east and north-west of the area described in chapter 8.2.2.3 in the districts of Namaqualand, Calvinia, Kenhardt and Gordonia. Topographically, both areas form part of the Bushmanland Plateau with large pans and vloers, and a smaller portion, of broken veld near the Orange River.

Results from a total of 1 030 boreholes in this group were analysed. In comparison with the previous group, the percentage of successful boreholes is slightly higher, and the percentage of total failures lower, namely 26,3 per cent compared to 22,1 per cent, and 51,1 per cent compared to 55,8 per cent respectively (Fig. 55(b)). Only 4,7 per cent of the boreholes yielded more than 4,5 m^3/h, which is practically the same as for the previous group.

The highest percentage of boreholes yielded water between 15 and 30 m (Fig. 56(b)), which is appreciably shallower than in the previous group. Sixty-two per cent of all the boreholes, and

65 per cent of the successful boreholes yielded water between 15 and 60 m (Fig. 57(b)), which are nearly the same percentages as for the depth interval 30 to 90 m in the previous group.

The cumulative graphs (Fig. 58(a)(ii) and Fig. 58(b)(ii)) show that 80 per cent of the water was struck shallower than 75 m and 92 per cent shallower than 105 m. In the case of successful boreholes the percentages for the same depth intervals were 83,6 and 94 respectively. The rest levels (Fig. 59(a)(ii) and Fig. 59(b)(ii)) were also appreciably shallower than for the previous group, viz. 86 per cent shallower than 60 m, increasing to 91,3 per cent for the same depth interval in the case of successful boreholes. In 20 per cent of the successful boreholes the rest levels were deeper than 45 m, while in the previous group 37,5 per cent were deeper than this level, and 20 per cent were deeper than 63 m.

Due to the fact that water was struck in a high percentage of boreholes at a shallower depth than in the previous group, the confining pressure is even less. In 50 per cent of the boreholes (Fig. 60(a)(ii) and Fig. 60(b)(ii)) water was struck less than eight m below the rest level. In the case of successful boreholes the percentages were very similar.

The histograms in Figs 61(b) and 62(a) show that in 17,1 per cent of the total of 397 boreholes, water was struck between the depth of weathering and 6 m shallower than this depth. In 63,7 per

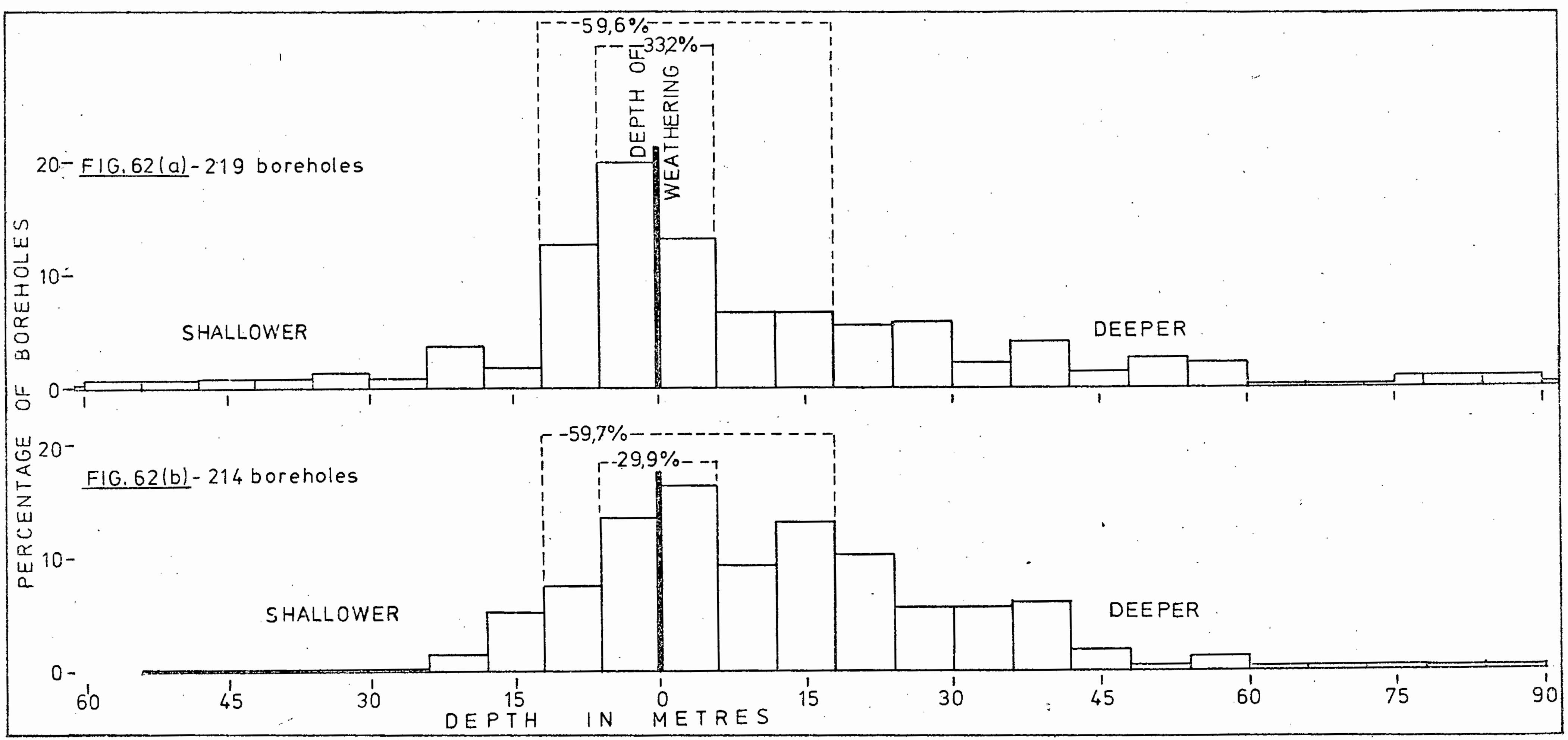


FIG. 62 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK IN SUCCESSFUL BOREHOLES RELATIVE TO THE DEPTH OF WEATHERING WITH AVERAGE ANNUAL RAINFALL OF (a) 100-150 mm; (b) 150-200 mm; GREY GNEISS, N.W. CAPE PROVINCE.

cent water was struck deeper than the depth of weathering, and 50,9 per cent yielded water between 12 m shallower and 18 m deeper than this depth. In the case of successful boreholes the percentages for the above depth intervals were 20 per cent, 56,7 per cent, and 59,6 per cent respectively. As in the previous group, the boreholes with better weathering yielded better supplies.

8.2.2.5 GREY GNEISS WITH AVERAGE ANNUAL RAINFALL BETWEEN 150 AND 200 MM

Boreholes in this group were found in the more mountainous foothills of the Kamiesberge in Namaqualand, to the east of Kenhardt in the Kenhardt and Prieska Districts, and to the north of Keimoes in the Gordonia District. Topographically the surface was more broken than for the previous groups, and outcrops of solid rock were more numerous. Relief was slightly more pronounced, and drainage channels better developed. The major portions, however, still formed part of the Bushmanland Plateau. Records of 742 boreholes in this group were traced.

In comparison with the previous groups, the percentage of successful boreholes (Fig. 55(c)) was much higher, namely 38,3 per cent. The percentage of totally dry boreholes was 39,6, compared to 51,1 and 55,8 per cent for the previous groups. Eight per cent of the boreholes yielded more than 4,5 m^3/h, which is nearly double the percentage in the previous groups.

In 77,2 per cent of the boreholes (Figs. 56(c) and 57(c)) water was struck between 15 and 60 m, and in 78,6 per cent of successful boreholes for the same depth interval. These are much higher percentages than for the previous group. From the cumulative graphs (Figs. 58(a)(iii) and 58(b)(iii)) can be seen that 84,5 per cent of all the boreholes and 88 per cent of the successful boreholes yielded water shallower than 60 m. Nearly all the boreholes, 97,2 and 98,2 per cent respectively, yielded water shallower than 90 m.

In 94,5 per cent of the boreholes the rest levels were shallower than 60 m, and in 98,4 per cent shallower than 75 m (Fig. 59(a)(iii)). In the case of successful boreholes the respective percentages were 97,5 and 98,8 (Fig. 59(b)(iii)). In 81 per cent of all the boreholes and in 91 per cent of the successful boreholes, the rest levels were shallower than 45 m. In the previous groups the percentages of boreholes for this depth interval were 62,5 and 80 respectively.

The shallow depth of the ground-water more than balanced the higher infiltration rate, so that confining pressure is still lower than in the previous group. In 70 per cent of the boreholes water was struck within 12 m of the rest level, and in 82 per cent within 18 m (Fig. 60(a)(iii)). Only 8,2 per cent of the boreholes yielded water deeper than 30 m below the rest level. This is exactly half the percentage in the previous group.

In 343 boreholes the depth of weathering could be correlated with the depth at which water was struck (Fig. 61(c)). In contrast with the two previous groups, the highest percentage of boreholes (17,5 per cent) yielded water between 0 and 6 m deeper than the depth of weathering. In 58 per cent of the boreholes water was struck between 12 m shallower and 18 m deeper than the depth of weathering. Twenty four per cent of the boreholes yielded water shallower than the depth of weathering and 21 per cent more than 30 m deeper than this depth. In the case of successful boreholes (Fig. 62(b)), the percentages for the same depth groups were 16,4; 59,7; 28,0 and 17,4 respectively. In this group the difference between successful boreholes and the total number of boreholes was not as obvious as in the previous groups. This can partly be explained by the much higher percentage of successful boreholes.

8.2.2.6 GREY GNEISS WITH AVERAGE ANNUAL RAINFALL MORE THAN 200 MM

Due to the fact that information was available from only 40 boreholes in this group, no effective comparison could be made with the previous groups. The percentage of successful boreholes was slightly higher than in the previous group, viz. 40 per cent. Because 20 of the boreholes were dry, the number of boreholes yielding water was too small to make any other calculations of scientific value.

8.2.2.7 GREY GNEISS UNDER A COVERING OF THE KAROO SYSTEM

The Archaean rocks are covered by flat-lying sediments of the Karoo System to the south of Kenhardt and the north of Upington. This cover usually consisted of tillite or shale of the Dwyka Series, but occasionally thin horizons of more arenaceous sediments were seen. Dolerite, both as dykes and sills, was found on several farms, e.g. Bastiaansvlei, Kenhardt District, and north of Keimoes, Gordonia District. Sometimes the Dwyka Series occurred in isolated outliers of a few hundred metres to a few kilometres in diameter. To the west of Kenhardt the continuous cover started at southern latitude 29°20' and extended southwards. To the north of Upington a large portion of the sediments of the Karoo System is covered by wind-blown sand.

In the areas where the cover of sediments was so thin that groundwater was struck in the underlying Archaean Formations, the boreholes are discussed in this chapter. In general this happened in areas where the cover of the Karoo System was less than 60 m thick.

A total of 170 boreholes were found for which the above conditions are valid. From the cumulative graph of the yield as a function of the total number of boreholes (Fig. 63) can be seen that 59,5 per cent of the boreholes were failures, and 36 per cent were totally dry. Eight comma nine per cent yielded more than 4,5 m^3/h, and 1,75 more than 13,6 m^3/h. These results are

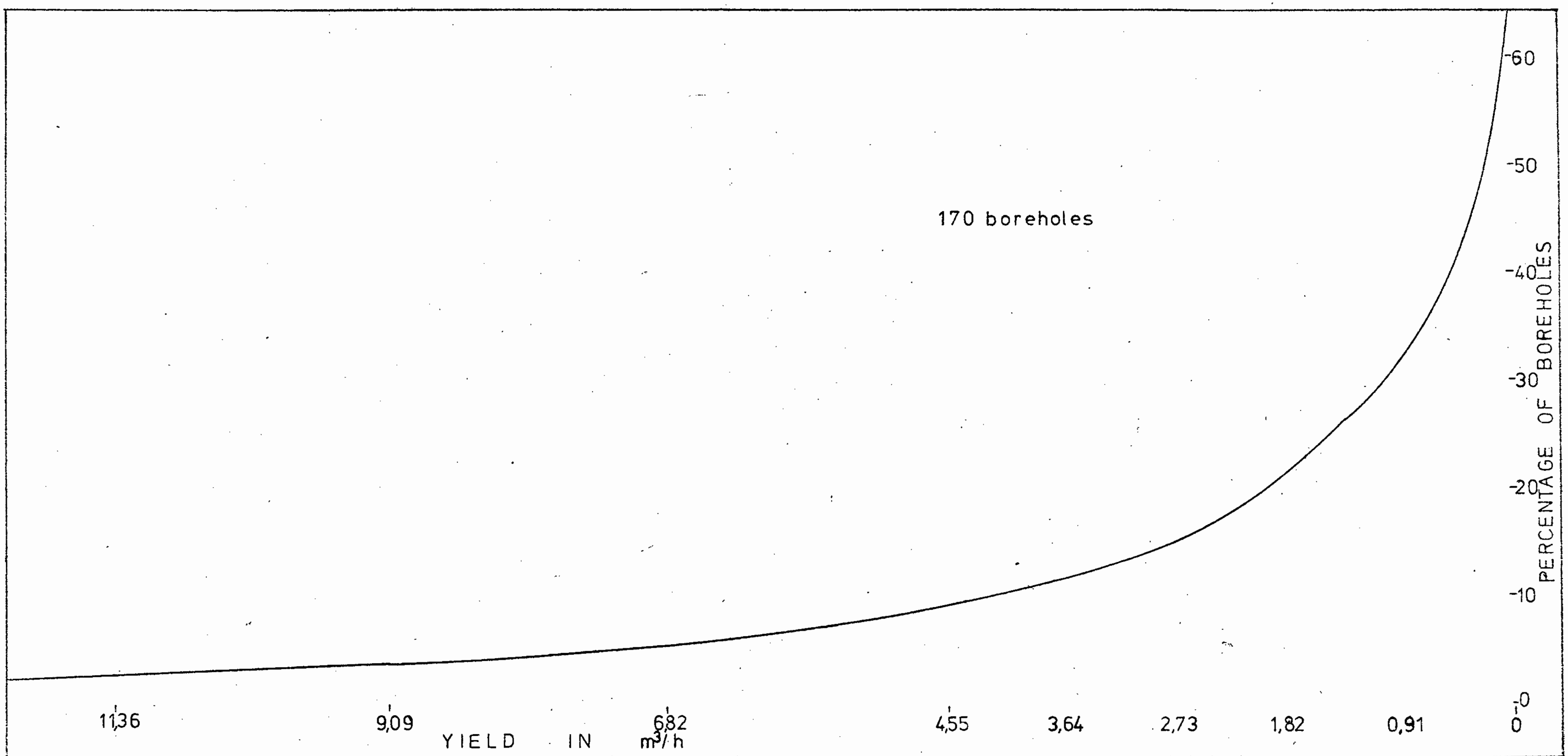


FIG. 63 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF THE NUMBER OF BOREHOLES; DWYKA SERIES COVER ON GRANITE AND GNEISS, N.W.CAPE PROVINCE.

better than for any of the groups discussed in chapters 8.2.2.2 to 8.2.2.6. This result was rather surprising, as the contact zone between the granite and the overlying Dwyka Series was not regarded as an aquifer by Vegter (1953) and others.

Histograms were drawn of the depth at which water was struck relative to the depth to solid granite (Figs. 64(a) and (b)). In 38,8 per cent of the boreholes water was struck within 12 m shallower and 6 m deeper than the contact. In the case of successful boreholes this percentage increased to 43,3. In the previous groups the depth at which water was struck was calculated relative to the depth of weathering. The highest percentages for the same depth interval were 35,2 and 37,4 per cent respectively. The Dwyka Series-Grey Gneiss contact can therefore be regarded as a good aquifer.

The percentage of successful boreholes relative to the depth to the granite contact is shown as a histogram in Fig. 65. The percentage of successful boreholes was less than 40 where the granite contact was at a depth of less than 45 m. For depth of 45 m to 90 m between 52 and 67 per cent of the boreholes were successful. Of the ten boreholes in which the contact was deeper than 90 m only two (20 per cent) were successful.

The histograms of the depth at which water was struck as a percentage of the number of boreholes (Fig. 66(a) and (b)), show that 30,3 per cent yielded water between 30 and 45 m, and 54,6 per cent

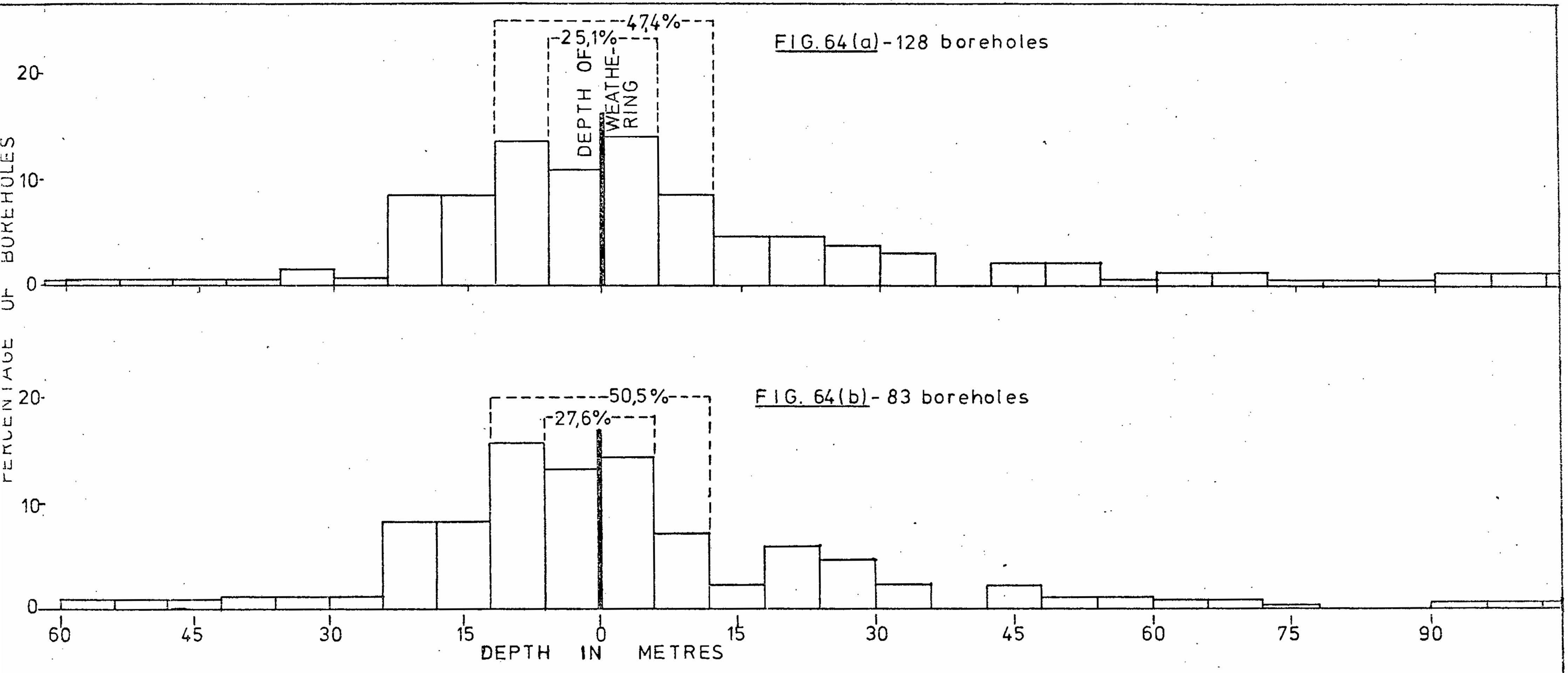


FIG. 64 - HISTOGRAMS OF THE DEPTH AT WHICH WATER WAS STRUCK RELATIVE TO THE DEPTH TO SOLID GRANITE IN (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; DWYKA SERIES COVER ON GRANITE AND GNEISS; N.W.CAPE PROVINCE.

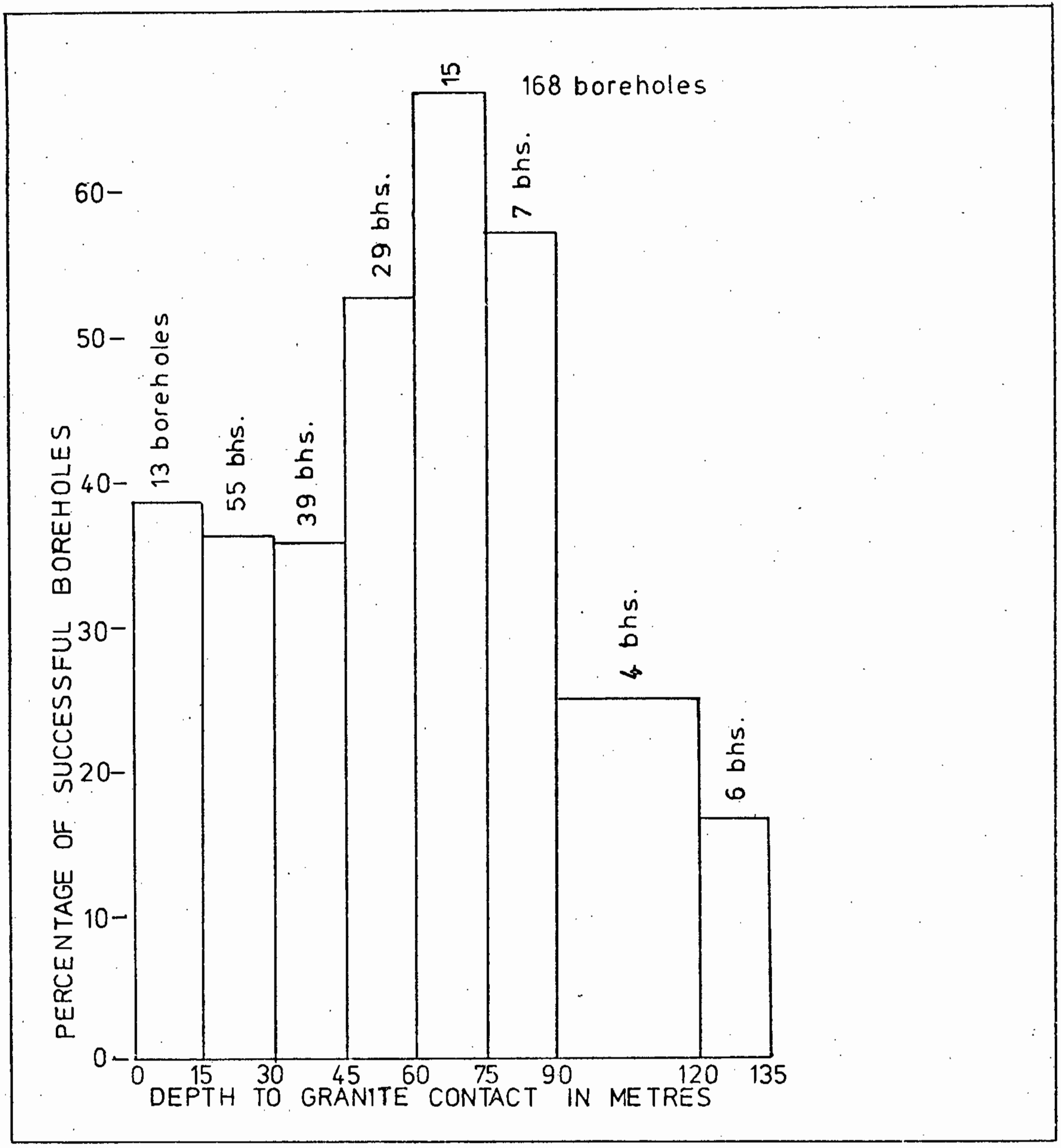


FIG.65 - HISTOGRAM OF THE PERCENTAGE OF SUCCESSFUL BOREHOLES IN EACH DEPTH GROUP WITH INCREASING DEPTH TO THE GRANITE CONTACT; DWYKA SERIES COVER ON GRANITE AND GNEISS, N.W. CAPE PROVINCE.

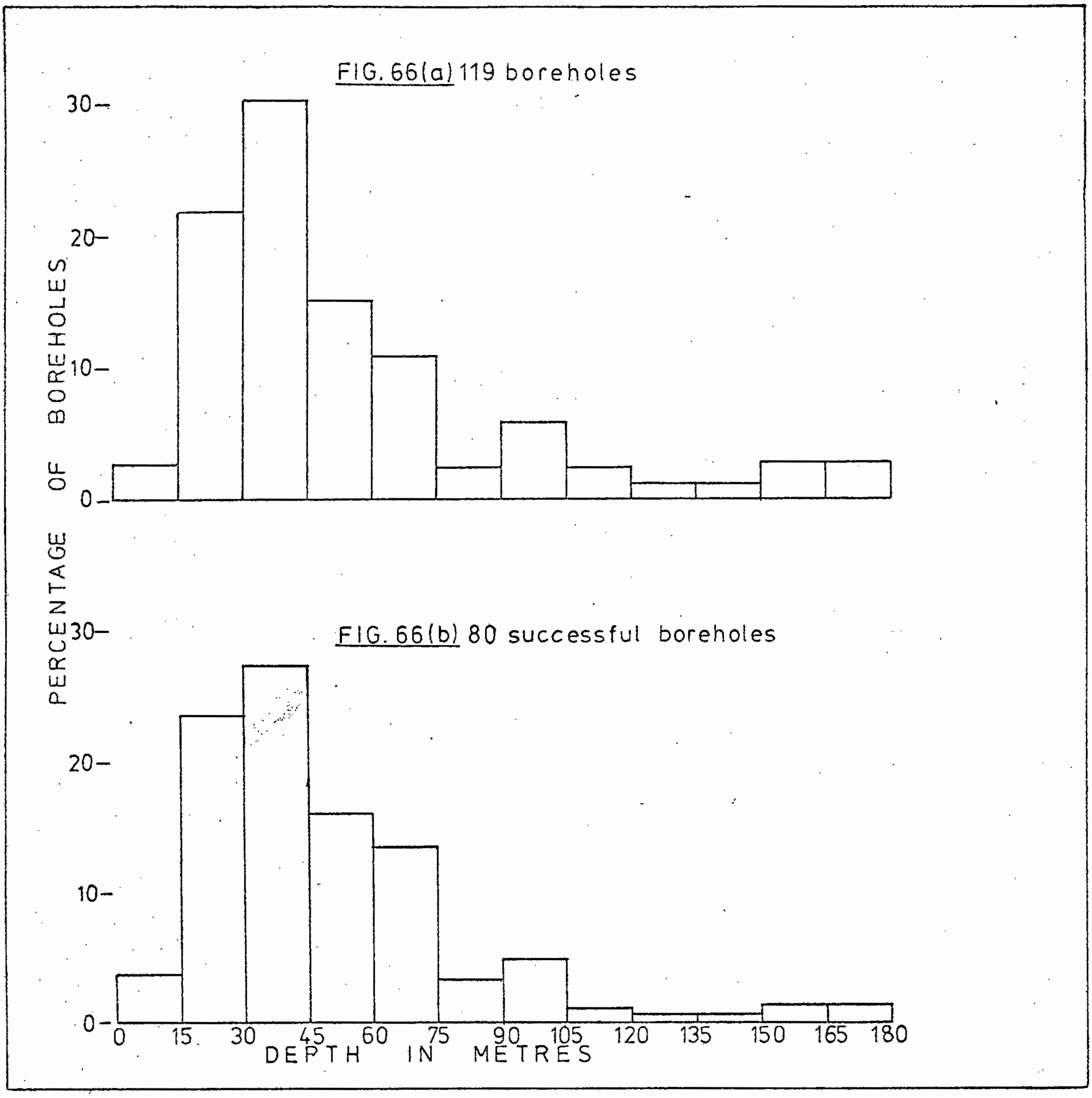


FIG.66 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; DWYKA SERIES COVER ON GRANITE AND GNEISS, N.W. CAPE PROVINCE.

shallower than 45 m. Between depths of 15 to 75 m 78,1 per cent of the boreholes yielded water. The respective percentages for successful boreholes were 27,5; 55,0 and 81,2.

In 37,5 per cent of the boreholes rest levels were between 15 and 30 m, and in 72,1 per cent shallower than 45 m (Fig. 67(a)). In the case of successful boreholes the respective percentages were 37,3 and 79,1.

In a high percentage of boreholes water was struck within 6 m of the rest level, viz. 32,3 per cent for the total number of boreholes, and 27,3 per cent for successful boreholes (Fig. 68(a) and (b)). In nearly 50 per cent of the boreholes (more than 52 per cent in the case of successful boreholes), however, water was struck deeper than 12 m below the rest level. These results are nearly the same as for the Grey Gneiss in areas with an average annual rainfall of less than 100 mm. This means that considerable confining pressure is encountered in the boreholes in spite of the shallow ground-water rest levels. This is due to the confining effect of the clayey sediments of the Dwyka Series.

8.2.2.8 SAND AND CALCRETE ON GRANITE AND GNEISS

An attempt was made to calculate the effect of a cover of sand or calcrete on the yield of boreholes in the granite and gneiss. Only boreholes where this cover was thicker than 3 m were taken into consideration.

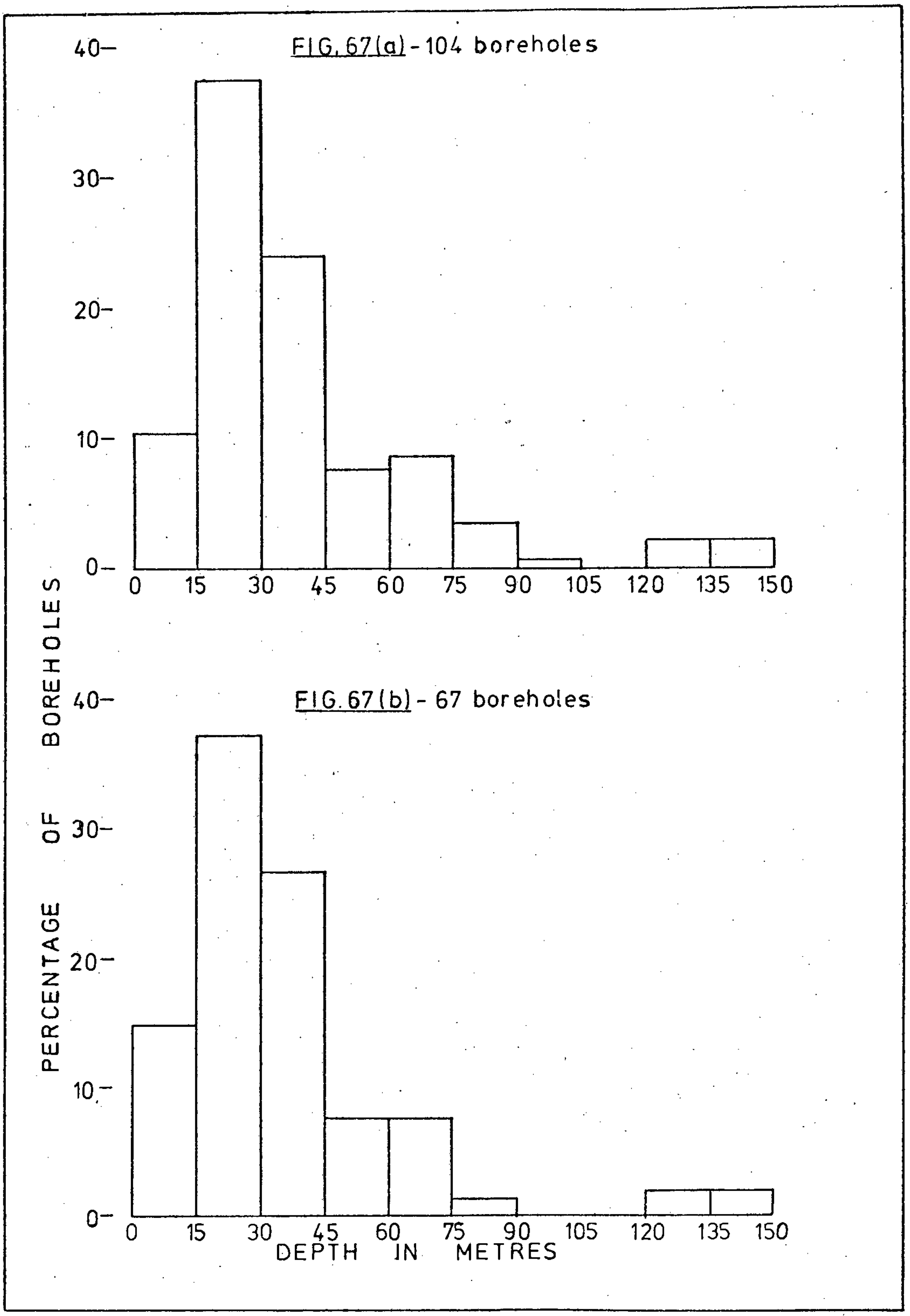


FIG. 67 - HISTOGRAMS OF REST LEVELS AS A PERCENTAGE OF (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; DWYKA SERIES COVER ON GRANITE AND GNEISS, N.W. CAPE PROVINCE.

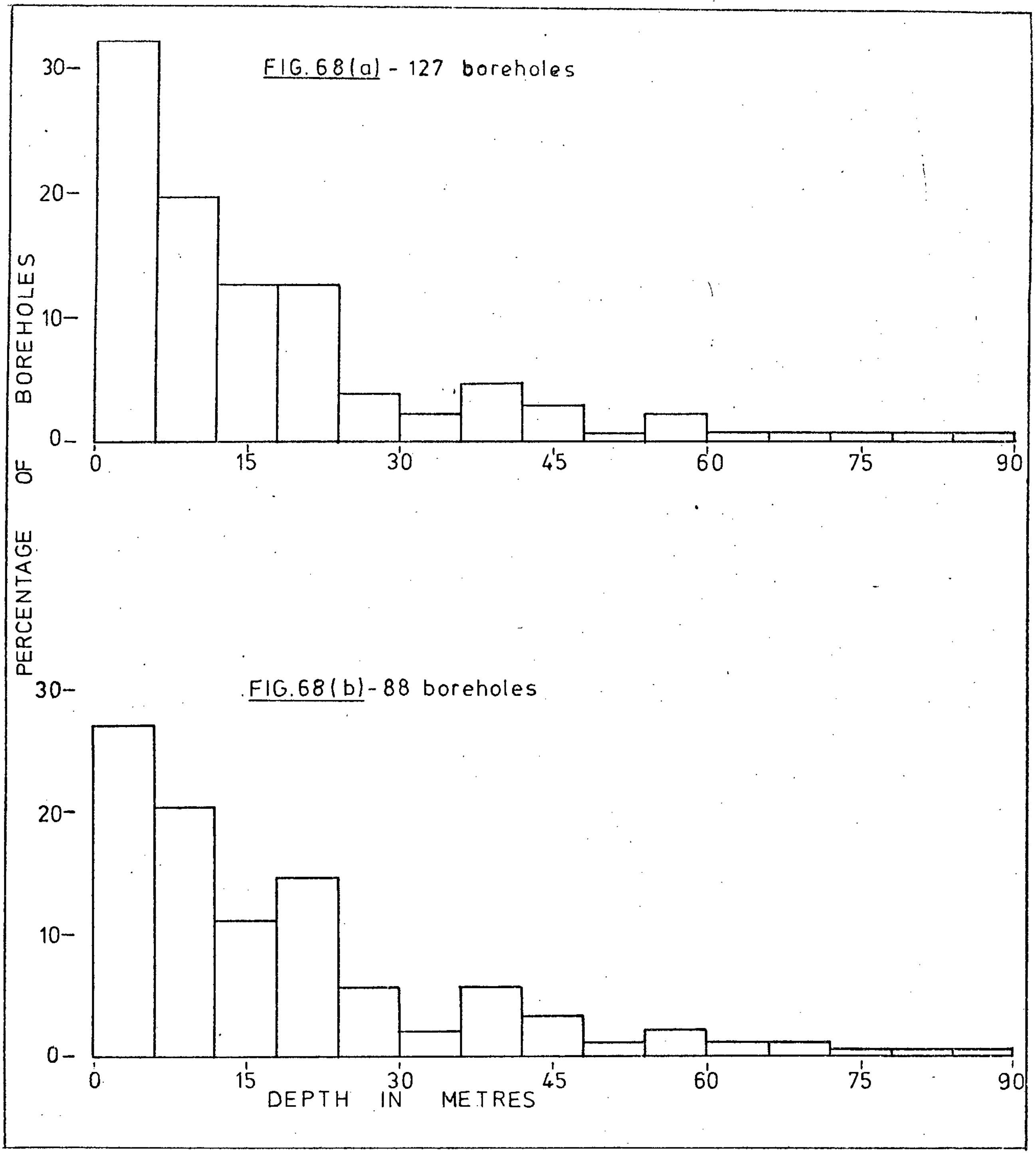


FIG. 68 - HISTOGRAMS OF DEPTH BELOW REST LEVEL AT WHICH WATER WAS STRUCK IN (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; DWYKA SERIES COVER ON GRANITE AND GNEISS, N.W. CAPE PROVINCE.

Of a total of 126 boreholes with a sand covering of 3 to 90 m, 39,7 per cent were successful. The histogram of the percentages of successful boreholes for different thicknesses of sand is shown in Fig. 69(a). The highest percentage of success was found in boreholes where the thickness of wind-blown sand was between 6 and 9 m, viz. 64,5. The average percentage of success for thicknesses of 3 to 30 m was 43,3. The nine boreholes in which the thickness of sand was more than 33 m, were all unsuccessful.

In a total of 289 boreholes the cover of calcrete on granite or gneiss was thicker than 3 m, with a maximum of more than 60 m. The histogram of the percentages of successful boreholes for different thicknesses of calcrete, is shown in Fig. 69(b). The percentage of successful boreholes was an average of 43,8 per cent between thicknesses of 3 and 24 m, with the highest percentage of 60 between 18 and 21 m. The average percentage is practically the same as for a cover of wind-blown sand of 3 to 30 m. For a cover of calcrete of more than 24 m in thickness, only three of a total of thirteen boreholes (23 per cent) were successful.

Boreholes in which the cover of calcrete or sand was less than 24 or 30 m had, therefore, a higher percentage of success than where no such cover was found. On the other hand very few boreholes yielded water where this cover became thicker than 27 to 30 m. These results can be explained by the high permeability of a sand or calcrete cover, but where it becomes too thick, the

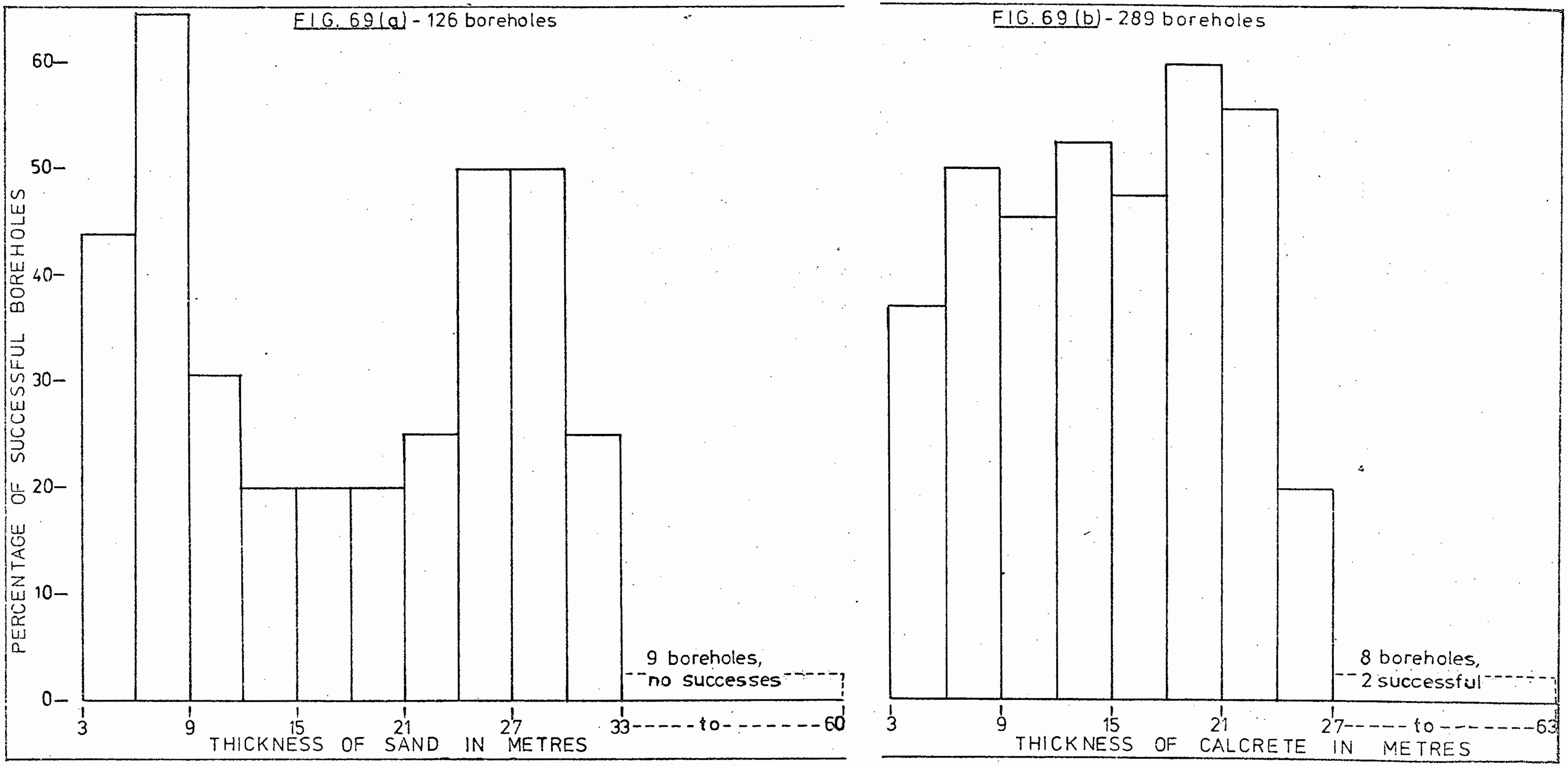


FIG. 69 - HISTOGRAMS OF THE PERCENTAGE OF SUCCESSFUL BOREHOLES IN EACH DEPTH GROUP WITH INCREASING THICKNESS OF (a) WIND-BLOWN SAND; (b) CALCRETE; ON GRANITE AND GNEISS; N.W. CAPE PROVINCE.

infiltrating water is retained in the cover and evaporated or transpirated without percolating down to the ground-water reservoir.

8.2.3 THE EFFECT OF DYKES

Outcrops of dykes and sills were very scarce in the granitic rocks in the North-western Cape Province, except in the broken country near the Orange River. On the extensive Bushmanland Plateau indications of the presence of dyke-rocks were rare, except where the older rocks were covered by relatively thick sediments of the Karoo System; for the greater part outside the area under discussion. Only a very limited number of boreholes were drilled next to or near the contacts of dykes in granite or gneiss. The dykes are of different geochronological ages, and the results of the few boreholes drilled near them, are discussed separately.

(i) Dykes of basic to ultrabasic composition were found in the granitised sediments of the Kheis System over a wide area. They were usually of small width, and were folded during the 1 000 m.y. orogeny, so that they occurred as short, disjointed and irregular outcrops, without preferred strike. Two boreholes were drilled within 10 km of the Orange River on Blaauwboschpan in the Kenhardt District, next to outcrops of these dykes in a broad laagte. Water was struck at shallow depths of 15 to 18 m and both boreholes were successful, whereas other boreholes in the same laagte were failures. These dykes, therefore, acted as barriers to the flow of underground water under the favourable circumstances in the laagte.

(ii) Dykes of post-Matsap age have a much wider distribution over the whole of the area under discussion, as well as further to the west and east. They were discussed by Gevers et al (1937), Leube (1959), Middlemost (1964), Von Backström and De Villiers (1972) and others. Their preferred direction of strike is between north-east and north-west over the whole area. They are usually of diabasic composition, but may be ultrabasic or syenitic. The results of nine boreholes drilled within 100 m of diabasic dykes, were traced in the Kenhardt, Prieska, and Namaqualand Districts. All of them were successful, with yields ranging between 0,45 and 10,45 m^3/h. The boreholes were drilled to depths of 8 to 159 m, and water was struck between 8 and 55 m. The rest levels varied between 3 and 49 m. All of the boreholes were drilled in laagtes with the dykes acting as barriers to the flow of underground water. These dykes, therefore, seem to control the flow of underground water, and can be useful in the locating of successful boreholes.

(iii) Adamellite dykes were found in the Keimoes area and further to the south-east. They were up to 15 m wide and some of them could be followed for long distances. The preferred direction of strike was between north-east and north-west. The contacts of these dykes were not jointed or sheared, and no successful boreholes were located next to adamellite dykes.

(iv) Dolerite dykes and sills were found over a large portion of the area under discussion. Von Backström (1964) and the author (1963) traced a large dyke striking east-west in the vicinity of Keimoes, over a distance of 36 km. The author (1963) mapped several swarms of dolerite dykes further to the east, striking between NNE and ENE. To the west and south of Kenhardt dolerite occurred as dykes or sills in the basal portions of the Dwyka Series and in the underlying granitic rocks. The preferred strike of these dykes varied between north and north-west.

Water was found in or near to dolerite dykes, but several of the boreholes were failures. Of a total of fourteen boreholes which could be traced, eight (57 per cent) were successful. Four of the six failures were stopped before the ground-water rest level was reached, or dolerite was struck above the rest level and the borehole was stopped before the solid dolerite was penetrated. If these boreholes are eliminated, 80 per cent of boreholes near dolerite dykes were successful. It is, therefore, necessary to exercise care in the selection of borehole sites near dolerite dykes, and geophysical surveys to locate the contacts of the dykes and the depth of the rest level are preferred.

(v) In the western part of the area under discussion, numerous pipes of kimberlite and associated rock-types are found.

Very little is known of their hydrological properties, but the pipes are sometimes weathered to great depths, relative to the country rock. On the farm Nachas, Namaqualand District, a drilling site was selected on deeply-weathered kimberlite in a pipe situated on the slope of a low hill, after numerous dry or unsuccessful boreholes had been drilled in laagtes and on quartz-filled shear-zones. A supply of approximately 1 m^3/h was found at a depth of 63 to 75 m.

8.2.4 ANALYSES OF GEOPHYSICAL SURVEYS

8.2.4.1 ELECTRICAL RESISTIVITY

The apparent resistivity between the ground-water rest level and the depth at which water was struck, was calculated for 284 boreholes drilled in granitic rocks in the North-western Cape Province. Because many dry boreholes could not be located, 50 per cent of these boreholes were successful, which is higher than the average for the area. Certain deductions can, however, be made from the results.

The empirical method described by Enslin (1963) was used for calculations. Histograms of the resistivity in ohm m as a function of (a) yield and (b) percentage of successful boreholes, are given in Fig. 77. Due to the fact that a large number of boreholes yielded water in secondary structures below the depth of weathering, the correlation between resistivity and yield or

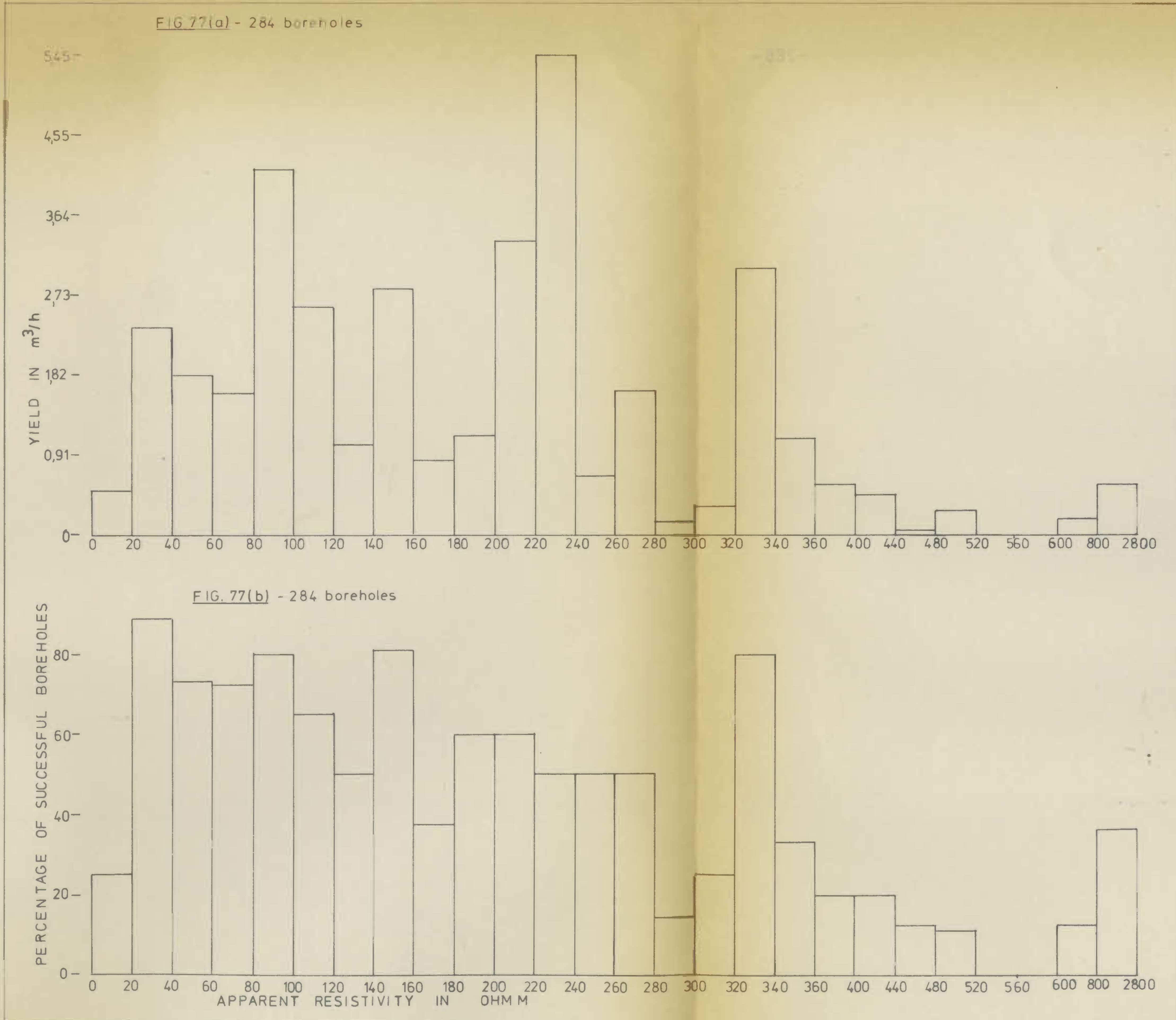


FIG.77 - HISTOGRAMS OF THE APPARENT RESISTIVITY AT THE GROUNDWATER REST LEVEL AS A FUNCTION OF (a) THE YIELD OF BOREHOLES; (b) THE PERCENTAGE OF SUCCESSFUL BOREHOLES; GRANITE AND GNEISS, N.W. CAPE PROVINCE.

percentage of successful boreholes was complicated. The average yield in the 184 boreholes in which apparent resistivity at and below the rest level varied between 20 and 280 ohm m, was 2,06 m^3/h (Fig. 77(a)). In the four boreholes in which the apparent resistivity was between 0 and 20 ohm m, and the 96 in which it was higher than 280 ohm m, the average yield was 0,51 m^3/h. In 37 boreholes in the ranges 80-100, 200-240, and 320-340 ohm m, the average yield was higher than 3 m^3/h, and in the case of individual boreholes, 40 yielded more than 3 m^3/h for apparent resistivities between 20 and 400 ohm m. It is obvious that no direct correlation can be made between yield and apparent resistivity, but a higher yield can be expected where the apparent resistivity is between 20 and 280 ohm m, than for higher or lower resistivities.

The percentage of successful boreholes (Fig. 77(b)) is higher than 50 per cent between 20 and 280 ohm m, and lower than 40 per cent outside this range except for the anomalies of the eight boreholes between 160 and 180 ohm m, and the five boreholes between 320 and 340 ohm m. If information from more boreholes could be added, these anomalies might be eliminated. The average percentage of successful boreholes for the 184 boreholes with average resistivities of 20 to 280 ohm m was 65 per cent, and outside this range it was 22 per cent for 100 boreholes. This contrast is large enough to conclude that the possibility of striking a successful supply of ground-water in the granitic rocks of the

North-western Cape Province is much higher where the apparent resistivity is between 20 and 280 ohm m than outside this range. If this range is subdivided it is found that for apparent resistivities of 20 to 160 ohm m (124 boreholes) the average percentage of successful boreholes was 71, and the average yield 2,21 m^3/h. For 60 boreholes with apparent resistivities between 160 and 280 ohm m, the average yield was 1,74 m^3/h, and 53 per cent were successful. All other parameters being equal, the highest probability of striking a successful supply is, therefore, found where the apparent resistivity at the ground-water rest level and deeper,is between 20 and 160 ohm m.

Apparent resistivity was measured at 57 boreholes where sediments of the Karoo System cover the granite and gneiss. Because of the smaller number of boreholes, the analysis could not be made as detailed as in the previous group. Histograms of apparent resistivity as a function of (a) yield, and (b) percentage of successful boreholes is shown in Fig. 79. The yield (Fig. 79(a)) very decidedly decreased with increase of the apparent resistivity. In the case of the percentage of successful boreholes (Fig.79(b)) the difference is not so obvious, but the possibility of striking a successful supply is at a peak for apparent resistivity of less than 50 ohm m. No borehole with resistivity higher than 200 ohm m yielded a successful supply.

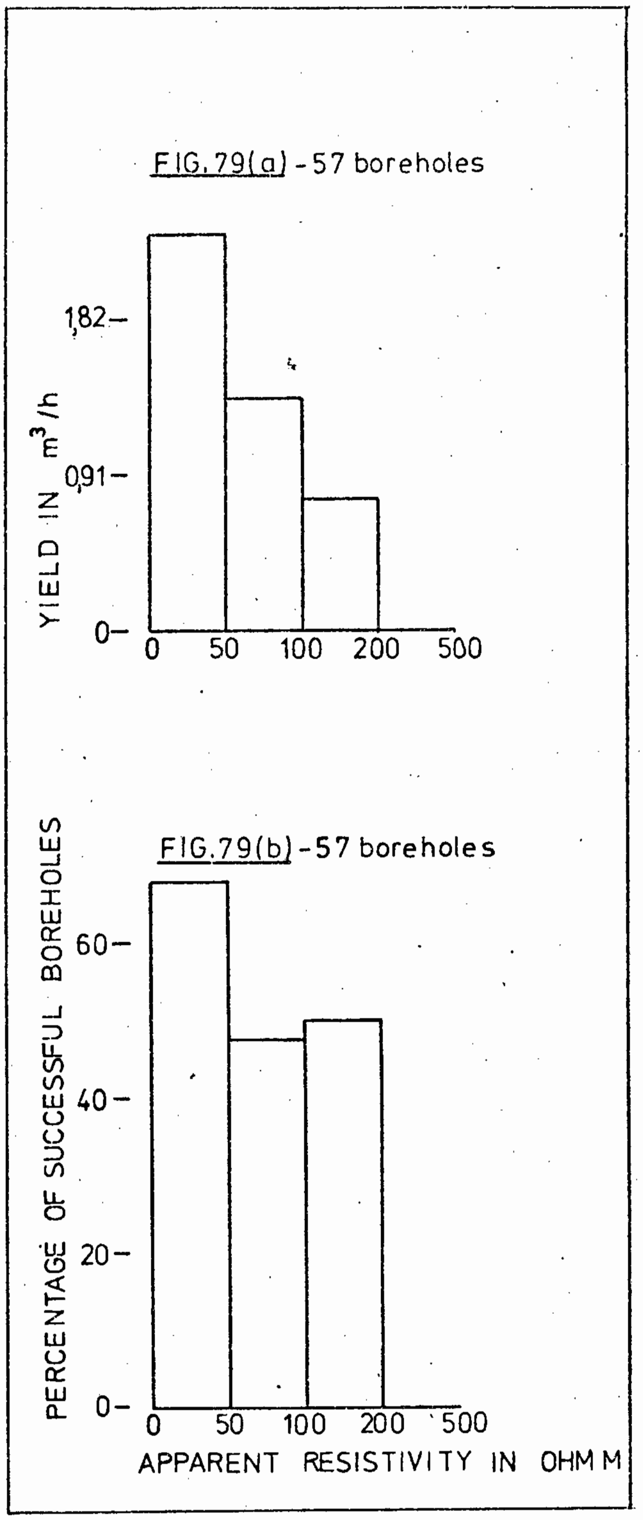


FIG.79 - HISTOGRAMS OF THE APPARENT RESISTIVITY AT THE REST LEVEL AS A FUNCTION OF THE (a) YIELD OF BOREHOLES; (b) PERCENTAGE OF SUCCESSFUL BOREHOLES; DWYKA SERIES COVER ON GRANITE AND GNEISS, N.W. CAPE PROVINCE.

8.2.4.2 ELECTRICAL BOREHOLE LOGGING

Electrical logging was done in 70 boreholes drilled in granitic rocks in the North-western Cape Province, of which 70 per cent were successful. This high percentage of successful boreholes is principally due to the fact that casing was usually removed from unsuccessful boreholes immediately after completion, with the result that the borehole collapsed and afterwards no measurements could be done in the borehole. The histograms of specific resistance between the ground-water rest level and the depth at which water was struck as a function of yield (Fig. 81(a)) and percentage of successful boreholes (Fig. 81(b)), demonstrate the absence of optimum values of the specific resistance. The average percentage of successful boreholes is 50 per cent or more over the whole range of specific resistances between 0 and 1 200 ohm m. The average yield between resistances of 60 and 600 ohm m is 2,42 m^3/h, compared to 1,26 m^3/h outside this range. The contrast is, however, too small to warrant any conclusions.

8.2.4.3 ELECTROMAGNETIC INVESTIGATION

Except for the work by Vegter (1953) described in Chapter 5.2.2.2.4, the electromagnetic method was used for the selection of water borehole sites only on the farm Vogelstruisbult, for use by the Prieska Copper Mines Ltd. The linear method as described by Vegter (1962) was used, and four borehole sites were selected, after anomalies traced by this method were checked for depth of

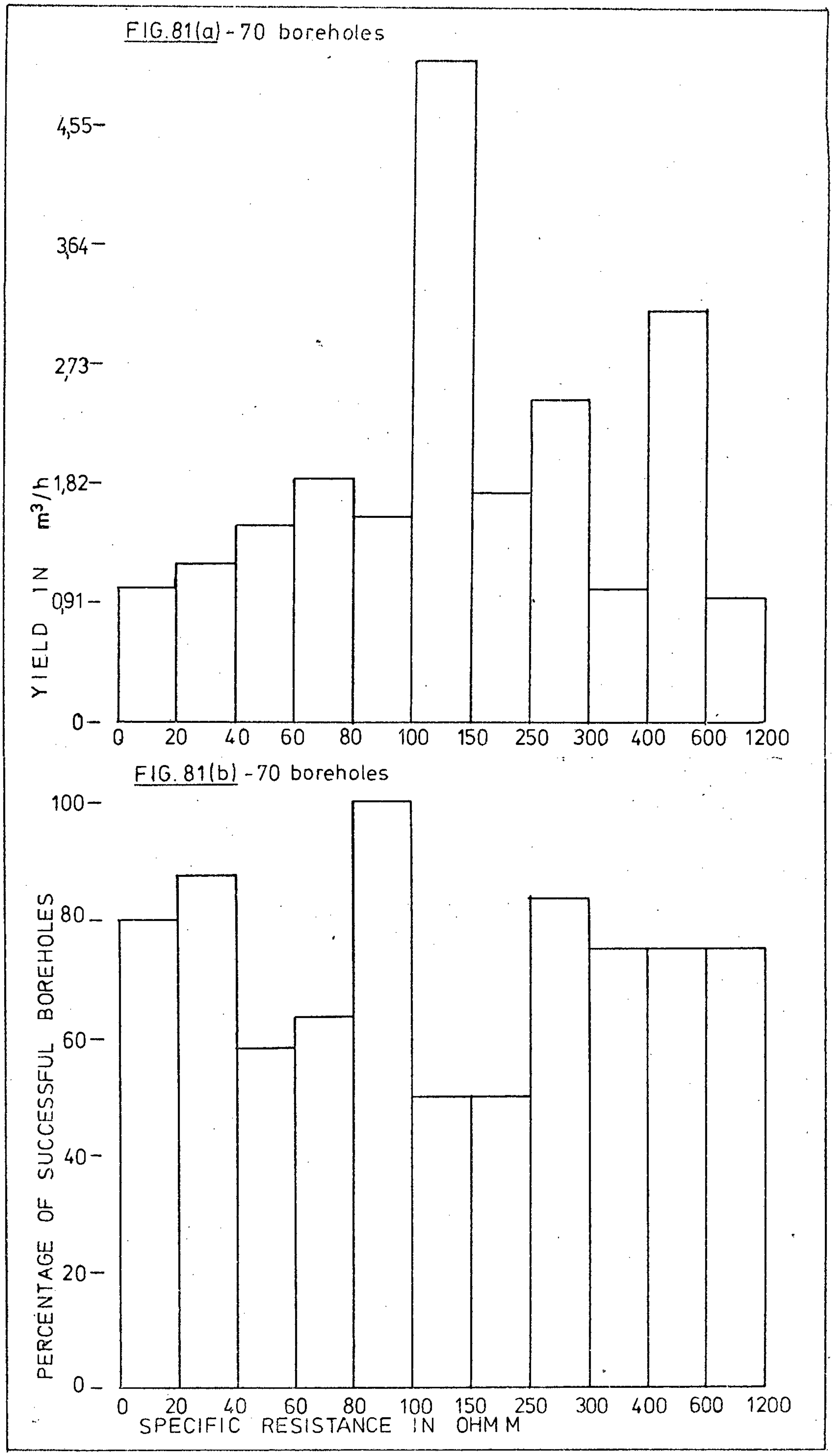


FIG. 81 - HISTOGRAMS OF SPECIFIC RESISTANCE AT THE REST LEVEL (as determined by borehole logging) AS A FUNCTION OF THE (a) YIELD OF BOREHOLES; (b) PERCENTAGE OF SUCCESSFUL BOREHOLES; GRANITE AND GNEISS, N.W. CAPE PROVINCE.

weathering by the electrical resistivity method. The four boreholes numbered 86 to 89 in Fig. 83 were drilled on these sites. Three of these boreholes (75 per cent) yielded more than 4,55 m^3/h, which was considered to be an economic supply for use by the mine. Of the 85 other boreholes drilled for water supply on this farm, ten yielded 4,55 m^3/h or more. Less than 12 per cent of the boreholes selected without geophysical investigations, therefore, yielded economic supplies, compared to the 75 per cent of successful supplies after electromagnetic and electrical resistivity investigations.

8.2.5 CONCLUSIONS

(i) The Geelbeksdam Granite is a much better aquifer than the Archaean Granite in the North-western Transvaal. This is probably due more to a favourable geographical position than to differences in lithological composition.

(ii) In the Grey Gneiss the percentage of successful boreholes is much lower, being lower than this percentage in the Archaean Granite in North-western Transvaal in areas with an average annual rainfall of less than 150 mm, but higher where the rainfall exceeds 150 mm.

(iii) There is a decided increase in the yield of boreholes and the percentage of successful boreholes in the Grey Gneiss, with increase of rainfall. This indicates a progressive higher recharge of ground-water with increase of rainfall.

(iv) With a cover of rocks of the Karoo System of 3 to 90 m in thickness on granite and gneiss, the percentage of successful boreholes and the yield of boreholes were higher than in areas without such a cover. The Dwyka Series-Grey Gneiss contact was proved to be a good aquifer.

(v) Where wind-blown sand or calcrete covered the Grey Gneiss, the percentage of successful boreholes was higher than in the previous groups, provided the cover was between 3 and 30 m thick. With a thicker cover, no water seem to reach the ground-water reservoir.

(vi) Dykes usually act as barriers to the flow of underground water, and can be useful aids for the selection of borehole sites.

(vii) Although no optimum figures for the apparent resistivity could be deduced, the possibility of striking a successful supply in the Grey Gneiss is almost three times as high for apparent resistivities between 20 and 280 ohm m than outside this range. Even higher yields and a higher percentage of success is probable for apparent resistivities of 20 to 160 ohm m.

(viii) Where a cover of the Karoo System is present, the best results were obtained with apparent resistivities of less than 50 ohm m.

(ix) Electro-magnetic surveys may be a very useful aid for the selection of borehole sites in this area, but so far very little work has been done with this aim in view.

9. GROUND-WATER ASSOCIATED WITH YOUNGER INTRUSIVES

9.1 TRANSVAAL

In the area north of the Witfontein Ridge the Archaean Formations were intruded by basic and acid rocks which were correlated with the Gaberone Pluton, and therefore, must be of post-Dominion Reef age. Outcrops were confined to the area south and west of Laastepoort 840, and a few small outcrops between Dwaalboom and Makoppa. The much younger Pilanesberg Complex was seen in this area only in the form of dykes.

9.1.1 GRANITE OF THE GABERONE PLUTON

If the small outcrop area of this granite is taken into consideration, a large number of boreholes have been drilled in it. Relatively complete records of 61 boreholes were analysed. Of these boreholes eighteen were drilled on Port Elizabeth 855, and the rest on twelve other farms. The granite usually was tough and unjointed below the depth of weathering, so that deep boreholes were the exception.

A cumulative graph of yield as a function of the percentage of the number of boreholes, is shown in Fig. 70. This formation is a poor aquifer, because 57,5 per cent of the boreholes were failures, and only 29,5 per cent yielded more than the minimum economic yield for this area. Only 8,2 per cent yielded more

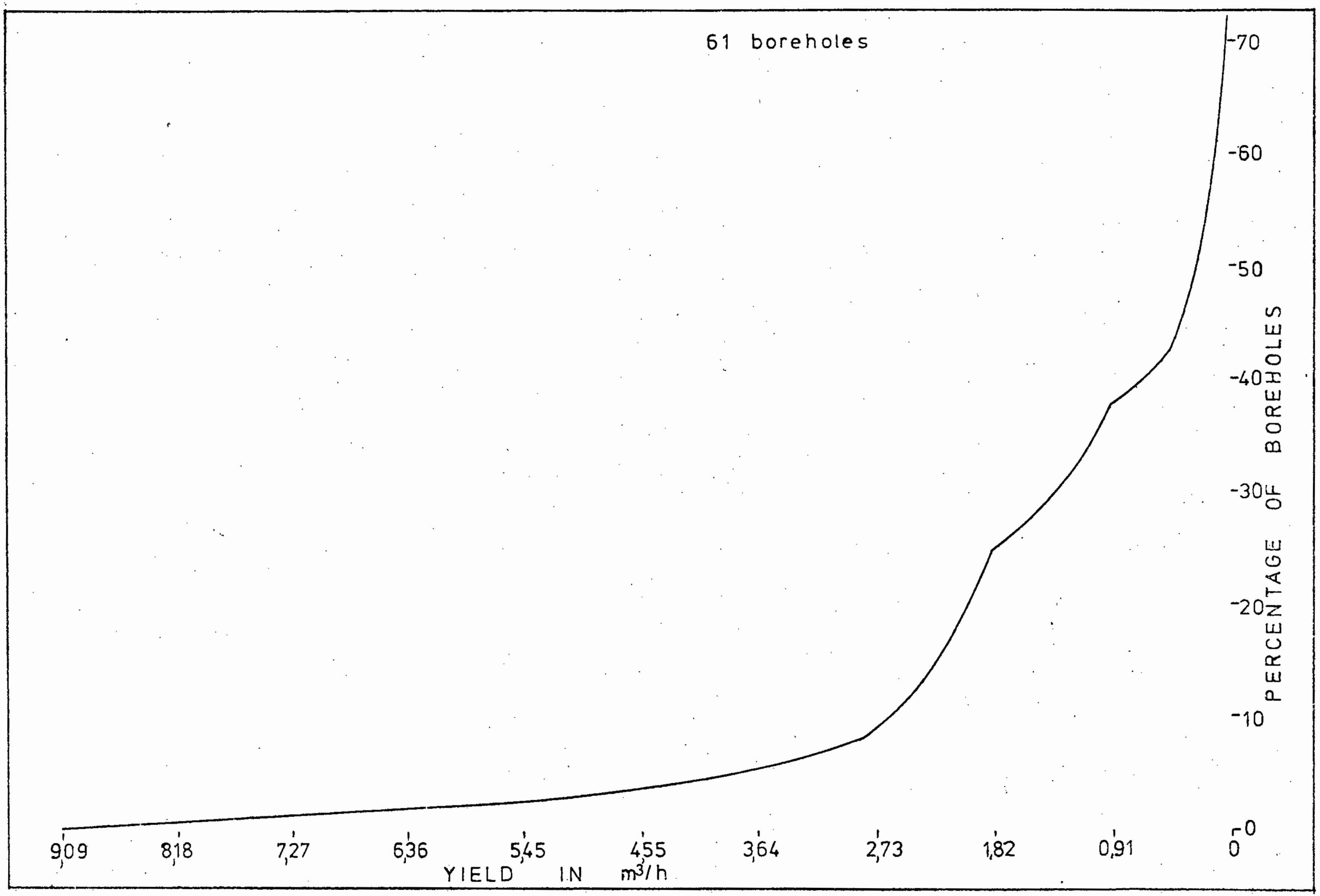


FIG.70 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF THE NUMBER OF BOREHOLES; GABERONE GRANITE, N.W.TRANSVAAL.

than 2,73 m^3/h, and none more than 9 m^3/h.

No water was struck shallower than 15m or deeper than 90 m, according to the histogram of Fig. 71(a). In the case of successful boreholes the limits were 15 and 75 m (Fig. 71(b)). Between depths of 30 and 60 m, 80,9 per cent of all the boreholes, and 93,1 per cent of successful boreholes yielded water. This means that the granite is often well-weathered, or jointed and permeable down to a depth of 60 m, but at greater depths it is practically an aquiclude.

The rest levels in all the boreholes were shallower than 75 m (Fig. 72(a)), 97,7 per cent of all boreholes and 96,2 per cent of successful boreholes having rest levels shallower than 60 m. In 73,1 per cent of the successful boreholes the rest levels were between 15 and 45 m.

There is consequently no great difference between the depths at which water was struck and the rest levels (Figs. 73(a) and (b)). In 42,5 per cent of the boreholes water was struck within 6 m of the rest level, and in 70,2 per cent within 12 m. For successful boreholes the equivalent percentages were slightly lower. It can, therefore, be concluded that this granite is less sheared than the older granite, and joints or other secondary structures does not extend far below the depth of the ground-water rest level.

It was therefore logical to expect that the largest number of boreholes would strike water shallower than the depth of

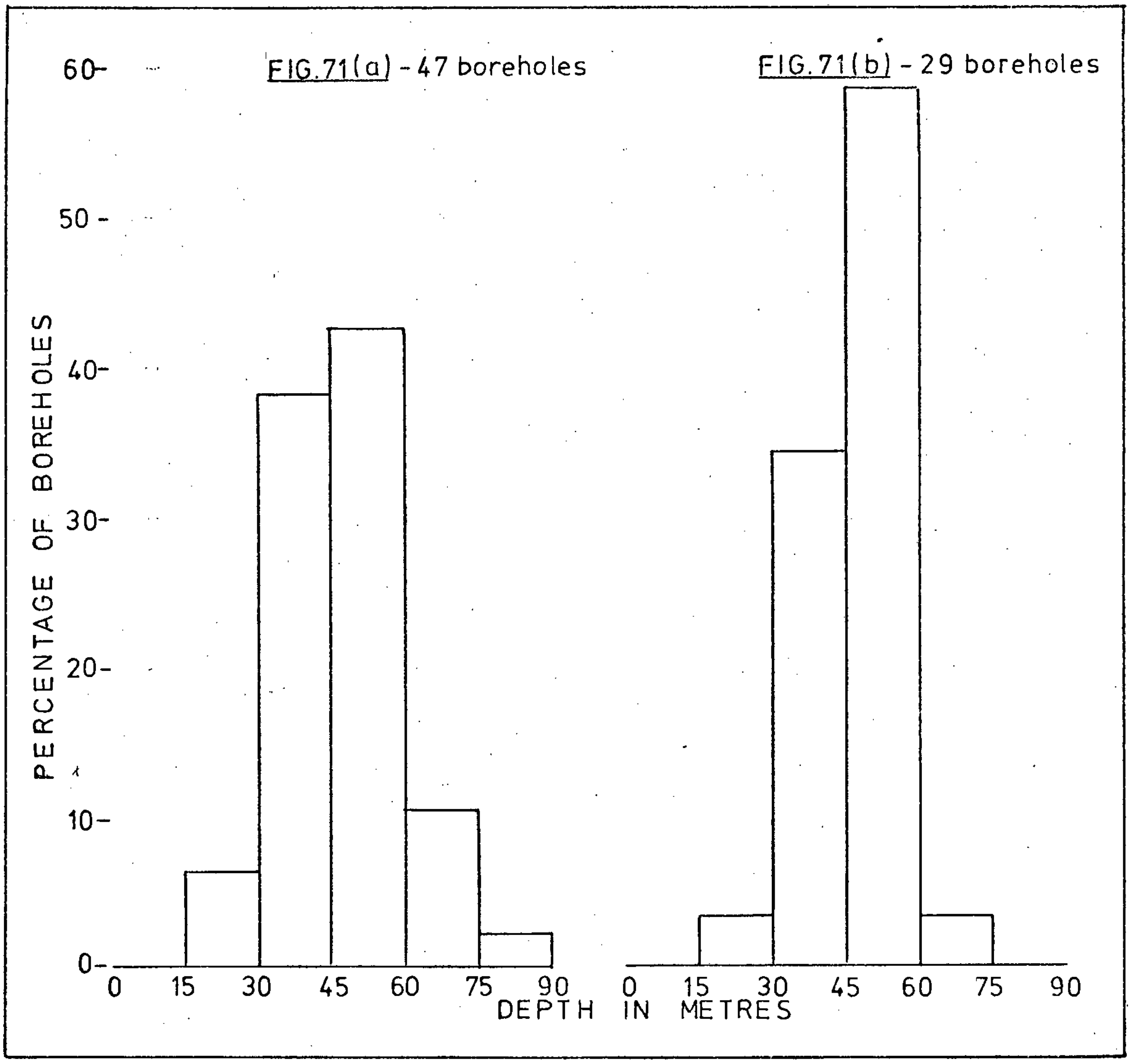


FIG.71 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK IN (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; GABERONE GRANITE, N.W. TRANSVAAL.

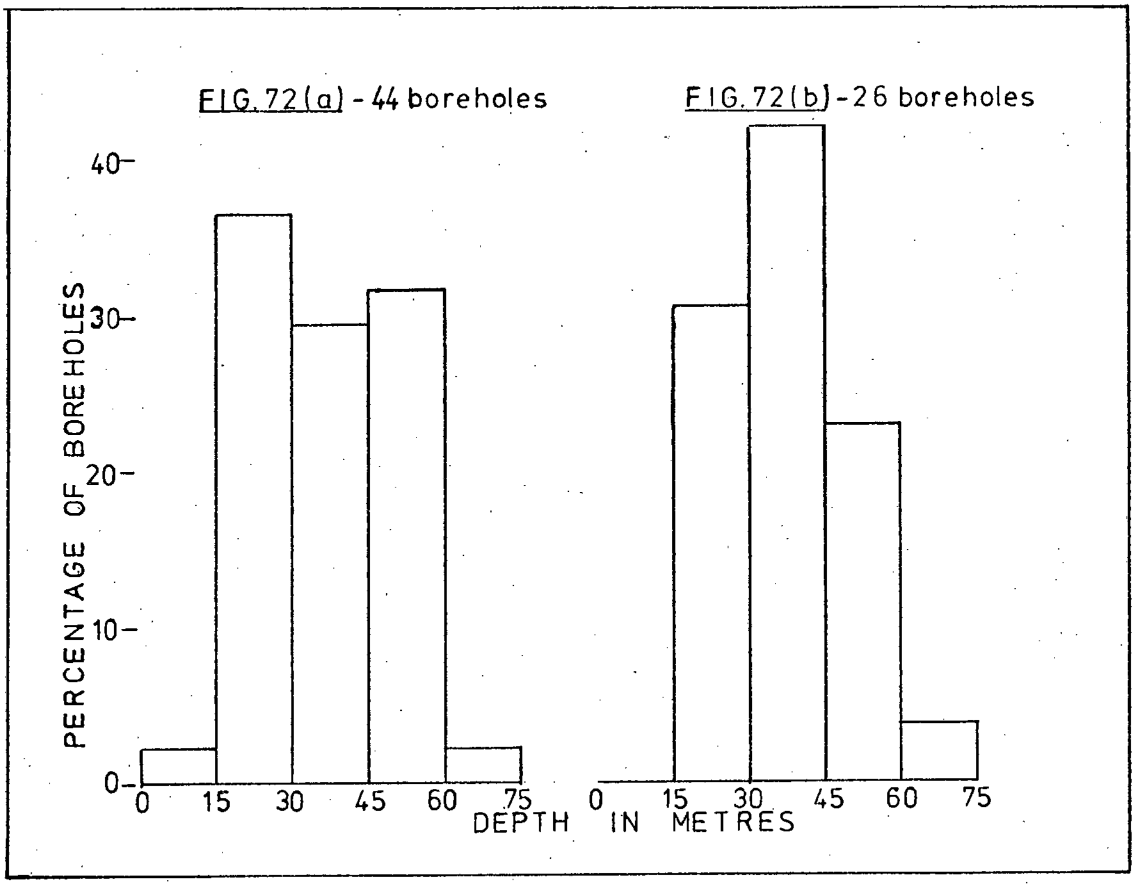


FIG. 72 - HISTOGRAMS OF REST LEVELS AS A PERCENTAGE OF (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; GABERONE GRANITE, N.W. TRANSVAAL.

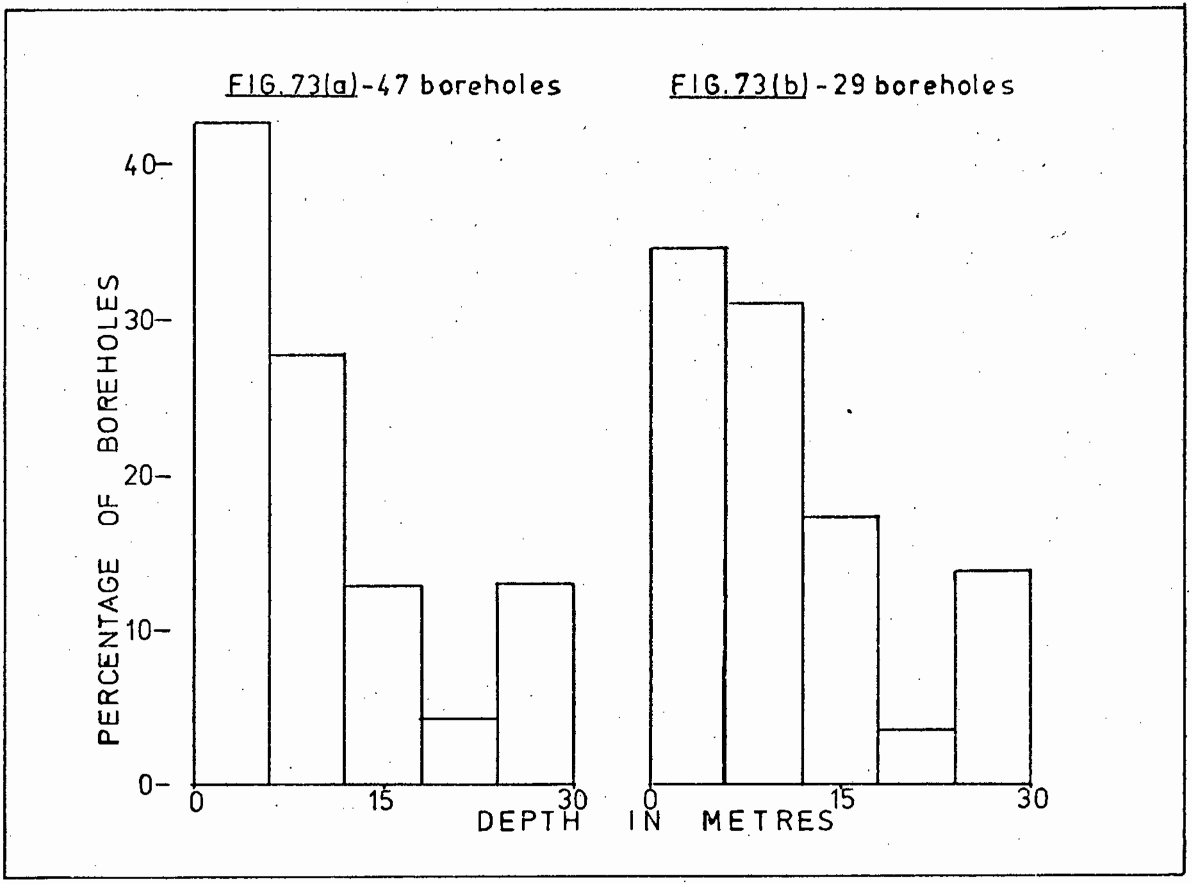


FIG. 73 - HISTOGRAMS OF DEPTH BELOW THE REST LEVEL AT WHICH WATER WAS STRUCK AS A PERCENTAGE OF (a) THE TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; GABERONE GRANITE, N.W.TRANSVAAL.

weathering, or very near to that depth. In the case of the total number of boreholes (Fig. 74(a)) 37,5 per cent of the boreholes yielded water shallower than the depth of weathering, and another 29,2 per cent within 3 m of that depth, giving a total of 66,7 per cent. Between 12 m shallower and 6 m deeper than the depth of weathering, 60,4 per cent of the boreholes yielded water. The equivalent percentages for successful boreholes (Fig. 74(b)) were 46,7; 76,7; and 60,0 respectively. Most of the supplies found deeper than 6 m below the depth of weathering were therefore small and uneconomical.

Graphs were drawn of the apparent resistivity at the groundwater rest level as a function of yield and percentage of successful boreholes. Between apparent resistivities of 20 and 90 ohm m, more than 50 per cent of the boreholes were successful, but the average yield was only 1,47 m^3/h, just over the economic minimum. Up to apparent resistivities of 140 ohm m the percentage of successful boreholes was higher than 30, but for higher resistivities only three out of a total of fourteen boreholes (21,4 per cent) were successful, and the average yield was 0,55 m^3/h.

The pronounced peak between 20 and 90 ohm m is due to the fact that water was struck in the weathered granite, or just below the depth of weathering. Good results can therefore be obtained by the electrical resistivity method in the selection of borehole sites.

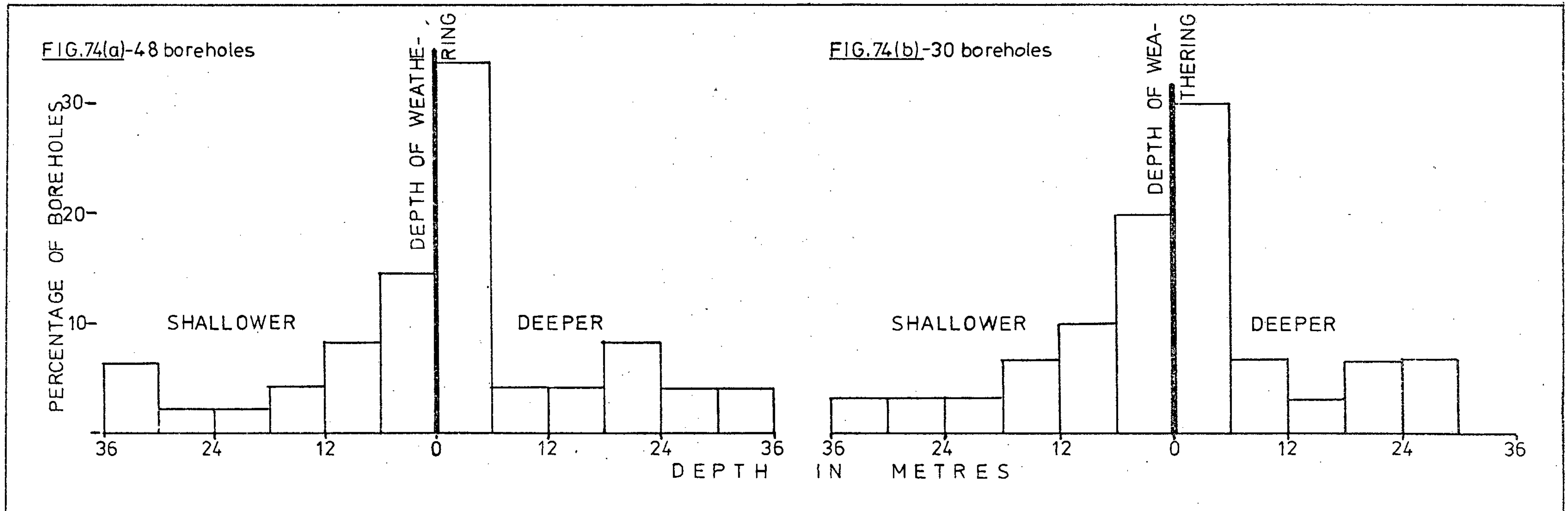


FIG.74 - HISTOGRAMS OF DEPTH AT WHICH WATER WAS STRUCK RELATIVE TO THE DEPTH OF WEATHERING IN (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; GABERONE GRANITE, N.W.TRANSVAAL.

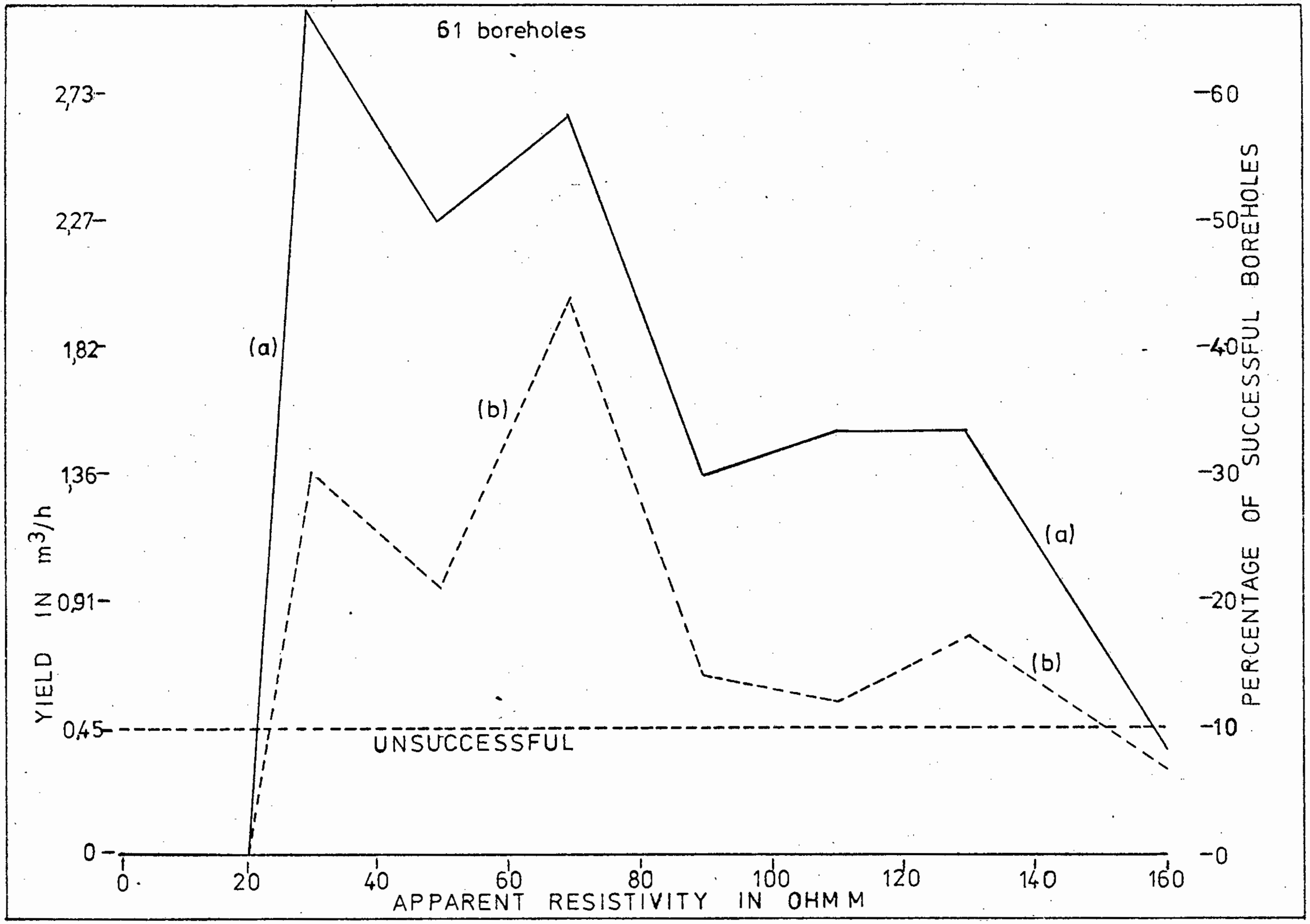


FIG. 75 - GRAPHS OF (a) PERCENTAGE OF SUCCESSFUL BOREHOLES; (b) YIELD OF BOREHOLES; AS A FUNCTION OF APPARENT RESISTIVITY AT THE GROUND-WATER REST LEVEL; GABERONE GRANITE, N.W.TRANSVAAL.

9.1.2 DYKES

Dykes with strong positive magnetic anomalies were traced on several farms viz. Doornlaagte 110, Laastepoort 840, Klipdrift 842, Engeland 862, Zwartebosch 863, and others (Fig. 11). These dykes had an east-west to north-east strike, and were of diabasic composition. They have been associated with the basic intrusions of the Gaberone Complex, and all of them were found near to the southern boundary of the outcrops of the Archaean Complex.

Very little is known about the water-bearing properties of these dykes. Of a total of nine boreholes drilled on or near to the dykes, six were failures, two yielded 0,68 - 1,13 m^3/h, and one, on Engeland 862, yielded more than 2,27 m^3/h. No conclusions of any scientific value can be drawn from these results.

9.1.3 PILANESBERG DYKES

The large number of dykes striking between north-west and NNW, which were traced by surface indications and geophysical means, are shown in Fig. 15. These dykes were of syenitic and doleritic composition and were associated with the Pilanesberg Intrusives. Very few outcrops were seen but the dykes could be traced over long distances by means of magnetometric surveys. In the south, between Spitskop 168 and Bloemendal 43 a density of approximately 1,5 dykes per km was maintained over a total distance of 24 km.

The type and amplitude of the anomalies across a dyke of Pilanesberg age on Smithfield 474 are shown in Fig. 10, with the boundaries of the dyke as interpreted from the results. Six boreholes were drilled across the dyke at Traverse II, and the results are shown in the same figure. Other anomalies across dykes of Pilanesberg age, and the results of drilling next to or in the dykes, are shown in Fig. 76.

As described in Chapter 8.1.5, twenty boreholes drilled in syenitic dykes were all failures. The weathered syenite was too clayey to act as an aquifer, and the unweathered syenite was not penetrated by secondary structures, such as open joints or shear zones, to a depth deeper than the ground-water rest level. The dykes, however, act as barriers to the movement of underground water. Fracturing in the Archaean Formations was probably also caused by the intrusion of the dykes, with the result that groundwater moved more freely near the dykes, and weathering was accellerated. The percentage of successful boreholes was, therefore, higher near to dykes than elsewhere. The optimum distance from the contact could not be calculated due to the scarcity of outcrops and the difficulty in determining, by geophysical means, the exact boundaries of dykes under a thick cover of soil or calcrete. On Smithfield 474 a borehole 21 m from the interpreted contact of the dyke yielded 6,55 m^3/h in weathered granite, on the side towards which the dyke dipped. On the other side of the dyke, small yields were struck in boreholes 75 and 105 m from the dyke.

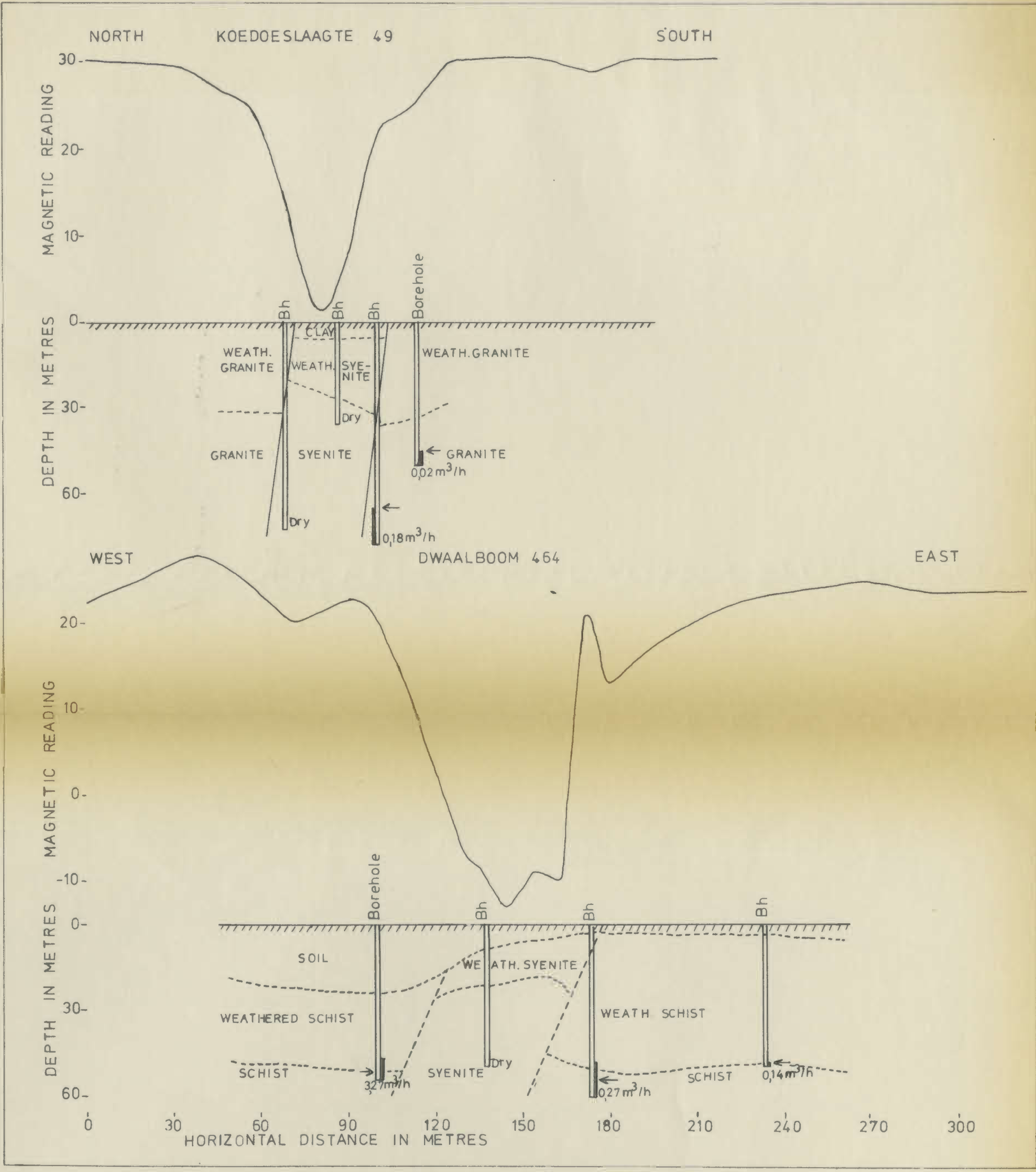


FIG. 76 - GRAPHS OF ANOMALIES ACROSS DYKES OF PILANESBERG AGE, AND CROSS-SECTIONS SHOWING POSITIONS OF BOREHOLES NEAR THE DYKES, SWAZILAND SYSTEM AND ARCHAEAN GRANITE N.W. TRANSVAAL.

A borehole on the contact was drilled in solid granite after passing through the syenite, and was dry (Fig. 10). On Koedoeslaagte 49 two boreholes striking the syenite above the rest level were dry, and two within 3 and 15 m of the dyke, on the side opposite towards which it dipped, yielded very little water in unweathered granite (Fig. 76). On Dwaalboom 464 a borehole 9 m from the dyke on the side towards which it dipped, yielded 3,27 m^3/h, in schist. Boreholes on the opposite side of the dyke yielded very little water at distances of 15 and 75 m from the contact. Geophysical surveys for the selection of borehole sites should therefore include resistivity surveys, after the dyke has been traced by a magnetometer.

9.2 CAPE PROVINCE

The younger formations intrusive into the Archaean rocks include adamellite, pegmatite, and dykes, sheets and sills which are post-Kheis to post-Karoo in age.

9.2.1 ADAMELLITE

The charnochitic adamellite porphyry described by Von Backstrom (1964) was found over large areas in the Gordonia and Kenhardt Districts, with the largest outcrops near Upington and Keimoes. It is a hard and compact dark-coloured rock which looks like a mafic rock in hand-specimens, usually with conspicuous grains of blue opaline quartz. It is usually emplaced in the form of phacoliths (Von Backström, 1964), but also occurs in the form of sheets or dykes, the latter showing chilled margins where it is exposed. Due to its hard and compact nature, and the fact that it was probably intruded during the later stage of deformation induced by the 1 000 m.y. orogeny, it weathers very slowly and contains a minimum of secondary structures. In spite of numerous outcrops, it is one of the most difficult formations in which to find adequate supplies of ground-water.

A total of 68 boreholes were traced which had been drilled in the adamellite. Of these a total of 56 (82,5 per cent) were totally dry, and a massive 94,1 per cent of all the boreholes were unsuccessful. The highest yield of any borehole in the adamellite was 1,54 m^3/h, and this borehole was drilled next to the Orange River on Neilersdrift, and had a shallow rest level. No borehole was drilled deeper than 120 m, and 84 per cent were shallower than 75 m. Boreholes were stopped at this relatively shallow depth due to the hardness and toughness of the rock, and the lack of cracks and joints.

In the twelve boreholes that yielded water, all the water was struck shallower than 63 m, and 19,7 per cent shallower than 55 m. The rest level in only one borehole was 63 m, and in all the others shallower than 40 m. These results again emphasise the shallow weathering and lack of secondary structures in the adamellite.

9.2.2 PEGMATITE

The bulk of the pegmatites were intruded into the Grey Gneiss, Pink Gneiss, and other reconstituted sediments of the Kheis System. They range from virtually concordant to markedly discordant (Hugo, 1969). The pegmatites were emplaced along fractures or joints in the intrusive rocks and along foliation and schistosity planes in the reconstituted sediments, or were formed by replacement of the country rock. The latter mode of emplacements applies to most of the giant homogenous pegmatites. No secondary structures were developed at the contacts of these pegmatites, but they may be of hydrological significance due to the difference in the rate of weathering in the pegmatite and in the country rock. The first type of pegmatite often showed joints or other secondary structures along its contacts with country rock. Shearing was sometimes seen in or across the pegmatite bodies. These structures sometimes acted as aquifers, with relatively high yields of ground-water. Where the pegmatite was weathered to a greater depth than the ground-water rest level, it also formed a good aquifer.

Unfortunately very few boreholes were drilled in pegmatite to depths below the rest level. Only sixteen such boreholes could be traced, of which 68,8 per cent were successful. The strongest supply was recorded from Kakamas in weathered pegmatite viz. 9,2 m^3/h. No borehole was drilled deeper than 120 m in pegmatite. Water was struck between 15 and 60 m, and the rest levels were between 15 and 45 m. The best results with the selection of borehole sites in pegmatite, were obtained where geophysical surveys showed adequate depths of weathering , or permeable secondary structures.

9.2.3 DYKES AND SILLS

Dykes and sills in the Grey Gneiss were discussed in Chapter 8.2.3, and the results will not be repeated here. Numerous dykes have also been traced in the Soetlief Formation and in the Transvaal System to the east and north-east of the area under discussion. The majority of these dykes strike between north-west and north, and belong to a group of diabasic, and occasionally syenitic, dykes. The dykes near Koegas were described by Leube (1959) as pre-Matsap, and are probably associated with the diabasic sheets intercalated with the Dolomite Series of the Transvaal System. The dykes in the Soetlief Formation probably belong to this group.

One spring on Kameelboom, Prieska District, issues from calcrete overlying the Soetlief Formation, in a laagte at the contact of one of these dykes. Nine boreholes were drilled within 50 m of the upsteam side of dykes in Soetlief lava. All of them were situated in or near laagtes, and all were successful. The average yield of the nine boreholes was 5,05 m^3/h, which is appreciably higher than the average yield from all the boreholes in the Soetlief lava.

Very few dykes have been traced in the quartzitic sediments of the Kheis System. Two dykes near Buchuberg Settlement strike north-east and are probably pre-Matsap, because they have been faulted due to the post-Matsap orogeny. A borehole was drilled next to each of these dykes. One of them was a failure.

In the area surveyed by the author swarms of dolerite dykes striking NNE to ENE were traced through granitic and quartzitic rocks, and through lava of the Marydale Series. Five boreholes drilled on Straussburg, Matjiesrivier and Gifkloof in the Marydale Series along three of these dykes, were successful. The dykes acted as barriers to the flow of underground water. On Bastiaansvlei, Kenhardt District a supply of 1,02 m^3/h was struck in weathered dolerite along an inclined sill in granite. Due to overpumping the rest level dropped from 27 to 52 m, and the supply has dwindled. Repeated drilling in the vicinity at later dates only succeeded in striking small uneconomic supplies.

9.2.4 CONCLUSIONS

(i) The granite of the Gaberone Pluton in the North-western Transvaal is a poor aquifer, due to a lack of secondary structures. Water is struck in weathered granite, or just below the depth of weathering. The percentage of successful boreholes is high where the apparent resistivities are between 20 and 90 ohm m.

(ii) Syenite dykes of Pilanesberg age act as barriers to the flow of underground water. Good supplies of water have been found on the side towards which the dyke dipped, but the results were poor on the other side.

(iii) The adamellite is one of the most difficult formations for the finding of successful supplies of ground-water in the North-western Cape Province, due to a lack of weathering and secondary structures. When borehole sites have to be selected, the adamellite should be avoided if possible.

(iv) In contrast pegmatites are good aquifers, provided the necessary precautions are taken to select a suitable depth of weathering or a permeable secondary structure.

(v) Boreholes near to dykes in the Archaean Formations have a higher probability of being successful than other boreholes. This statement seem to be particularly true for the Marydale and Soetlief lavas.

10. ZONES OF FAULTING, SHEARING AND FRACTURING AND THEIR ROLE AS AQUIFERS

10.1 TRANSVAAL

Due to the fact that almost no outcrops were found in this area, it was impossible to decide to what extent the occurrence of ground-water was associated with zones of faulting, shearing or fracturing, which will be called fracture-zones. Several north-west striking faults, and one striking north-south were mapped in the Dominion Reef System on the south-eastern edge of the Archaean Complex. These faults could not be traced into the area to the north because of the ubiquitous covering of soil and calcrete, so that it was impossible to decide how far they stretched. No boreholes were situated on or near to these faults where they were seen.

The brecciated shear zones, usually cemented by secondary quartz to a hard compact rock, were found striking in three main directions viz.

(a) East-west on Karoobult 613 and Doornlaagte 110

(b) North-west on Blinkwater 628 and Tarentaalpan 803

(c) West-southwest on Fairlawn 66 and Krugerspan 804.

A total of 16 boreholes were drilled on or near to these fracture-zones with the following results:

(a) Three boreholes were drilled on the quartz reefs formed by the quartz-cemented breccia. All three were dry.

(b) Two boreholes were drilled on the northern sides of similar quartz reefs, and both were failures.

(c) Nine boreholes were drilled between 6 and 60 m south or south-west of similar quartz reefs. Six were failures and only three (33 per cent) were successful, including the borehole on Tarentaalpan 803 which was drilled 60 m south of the quartz reef.

(d) On Blinkwater 628 the shear zone was visible as an elongated rise of calcrete. Two boreholes on this rise were successful, each yielding more than 2 m^3/h. The calcrete in this area was formed over sheared sediments of the Swaziland System.

The conclusion can be drawn that the silicified shear zones are not aquifers, but act as barriers to the movement of underground water. The general drainage is northwards, and all of the successful boreholes near fracture-zones were drilled on their southern sides. The exceptions were the boreholes on Blinkwater 628, on the fracture-zone striking north-west in sediments of the Swaziland System, and which was not cemented by secondary quartz.

10.2 CAPE PROVINCE

Because of the fact that outcrops are more numerous and continuous, a large number of linear structures, associated with lines of faulting, shearing, fracturing, and prominent jointing, could be distinguished in the North-western Cape Province. Vertical, inclined, or differential movement could be determined in some cases, but in a large number of the linear structures the geological evidence is too incomplete to deduce the type and degree of movement. There is a wide range in the age, strike, and dip of these structures, although a large precentage of them have steep dips. In general the shear zones striking in a northerly or north-westerly direction were near to vertical, while those striking east-west usually had a much lower angle of dip.

10.2.1 SURFACE INDICATIONS

Shear-zones were recognised on the surface by the following indications:

(i) Outcrops of secondary quartz, usually a white, milky low-temperature quartz. The quartz sometimes formed prominent ridges as on the eastern portion of Geological Sheet 207 (Keimoes) mapped by the author (1963). Several of them were 100 m or more in width, and were up to 20 km in length. On Kakamas and Keimoes Commonages and on Vryheid, east of Upington, well-developed crystals of amethyst were found in these quartz-filled fracture-zones. Epidote and calcite were frequently associated with the quartz. In several cases it was possible to distinguish two periods of quartz formation, denoting two periods of movement. Joubert (1971) found similar north-south fractures in Namaqualand, showing more than one period of movement.

(ii) In some of the fracture-zones quartz was subordinate to epidote. This was especially evident in an area from the Orange River near to the Aughrabies Falls, to the south-east towards Kenhardt and Marydale. The epidote-filled fracture-zones were usually narrower than the type described above, and much less prominent topographically. The open-jointed type were good aquifers, but a well-cemented type proved to be practically impervious to ground-water. These structures were usually short compared to the quartz-filled fracture-zones.

(iii) Mylonite or chertified mylonite usually occurred in shear zones, sometimes forming the most prominent constituents. It was usually associated with brecciated country rock which had a more reddish colour than the solid rock, probably due to colouring by iron oxides. Quartz and epidote were subordinate, and the mylonite was sometimes topographically prominent. These structures could seldom be traced for long distances, and had a tendency to be irregular in shape and width, and therefore could not always be recognised as linear structures.

(iv) A calcrete rise or depression on the surface, sometimes indicated a fracture-zone or other linear structure. Where such a rise or depression was not due to a dyke, it was usually found on major joints or fracture-zones along which no major movement took place, and where the ground-water rest level was shallow.

(v) Where an open-jointed linear structure was covered by soil, alluvium, or scree, it could sometimes be traced by a line of trees, shrubs, or denser bushes. This type of surface indication of fracture-zones was rare in the North-western Cape Province.

(vi) In some cases fracture-zones could be traced on air photos by a change in vegetation, soil or rock. Major faults could be traced in this manner, but other types of fracture-zones were seldom recognised by this means.

(vii) In several cases the only means of tracing open-jointed linear structures was by means of geophysical prospecting. The most promising methods were electro-magnetic and electrical resistivity, or a combination of these methods. Where there had been major movement along a fault the country rock on the two sides of the linear structure sometimes had different magnetic properties, and the structure could be traced by magnetic methods.

The geophysical procedures which had been developed to yield the best possibility of selecting a successful borehole, were the following:

(i) A reconnaissance survey by the linear electro-magnetic method to trace the location and strike of conductive zones.

(ii) To pinpoint the conductive zones more accurately, the circular method of electro-magnetic surveying, developed by Enslin (1955) was sometimes employed where no surface indications could be seen.

(iii) Resistivity depth probes to determine the degree of weathering along the conductive zone. Care was taken to site the electrodes as accurately as possible parallel to the strike of the linear structure. Centre-points were taken near to each other e.g. 5 to 10 m apart, and the differences in apparent resistivity were determined on a profile normal to the linear structure. Because of the limited width associated with fracture-zones the true depth of weathering or brecciation could seldom be determined. It was, however, possible to determine:

(a) the relative difference in weathering between the fracture-zone and the country rock ;

(b) the general direction in which the structure dipped.

From these results, and the depth to the rest level in the specific area, it was usually possible to determine whether the structure could yield water, and a boring site could be selected with a better than average possibility of striking a successful supply.

The following examples are given of the results of geophysical surveys:

(i) On the farm Stukkende Dam, Kenhardt District, several boreholes in the laagtes had started to dry up. Electrical resistivity depth probes proved that the rest level had declined until it was at the depth of weathering, and no sites could be selected with the hope of striking water in weathered granite. Secondary quartz outcrops were found on the west side of a high sand dune. The outcrop area was investigated by geophysical means, and it was found to be due to an east-west striking fracture-zone, which was permeable to a reasonable depth. A site was selected for drilling. After determining the strike of the fracture-zone, it was traced to the other side of the sand dune. Another site was selected approximately 5 km east of the former, after geophysical measurements. Both boreholes were successful.

(ii) On the farm Koenap, Kenhardt District, several fracture-zones with secondary quartz as major constituent were found, striking in different directions. Ten or more boreholes had been drilled on sites selected by boring inspectors, with the object of striking successful supplies of ground-water in them. All of the boreholes were failures. After geological and geophysical surveying a site was selected in 1949 on a zone striking N62W, and a strong supply was struck. In 1961 another supply was required on this farm, and after geophysical prospecting, a site was selected on another fracture-zone striking N66W. More than 2 m^3/h was struck at a depth of 90 m.

10.2.2 RELATIVE AGE AND STRIKE

The linear structures in the North-western Cape Province are of several different ages. Joubert (1971) recorded at least four events of deformation in Namaqualand which had shearing or faulting or both associated with them. Von Backström (1964) mentioned five orogenic periods in the Keimoes area with which deformation was associated. Some of the older structures were so completely recemented by secondary quartz or chertification of mylonite and breccia, that they had become impervious to the movement of ground-water and therefore of no hydrological importance.

From evidence collected in the field, the younger linear structures in the North-western Cape Province strike in many different directions. The results of 145 boreholes which were drilled on linear structures have been analysed with reference to the direction of strike of these structures. The results are shown in Fig. 84. From the histogram of Fig 84(a) can be seen that the percentages of successful boreholes did not vary appreciably in the different strike-directions, so that this criterion could not be used to deduce an age relationship for the different directions of strike. A much more detailed survey, with division of this large area into blocks, is necessary. The age relationship of the fracture-zones in each block might then be determined. The distribution of the number of fracture-zones in each direction of strike (Fig. 84(c)) was more unequal, but again no specific trend could be determined.

The strike of some of the fracture-zones changes direction appreciably, and in granite and gneiss some of the smaller linear structures meander both in strike and dip. It was found that many of the north-south striking fracture-zones were vertical and open-jointed, whereas most of the east-west and north-west structures dipped with different angles and were much less open-jointed. This was regarded as one of the reasons for the difference in the percentage of successful boreholes in different directions.

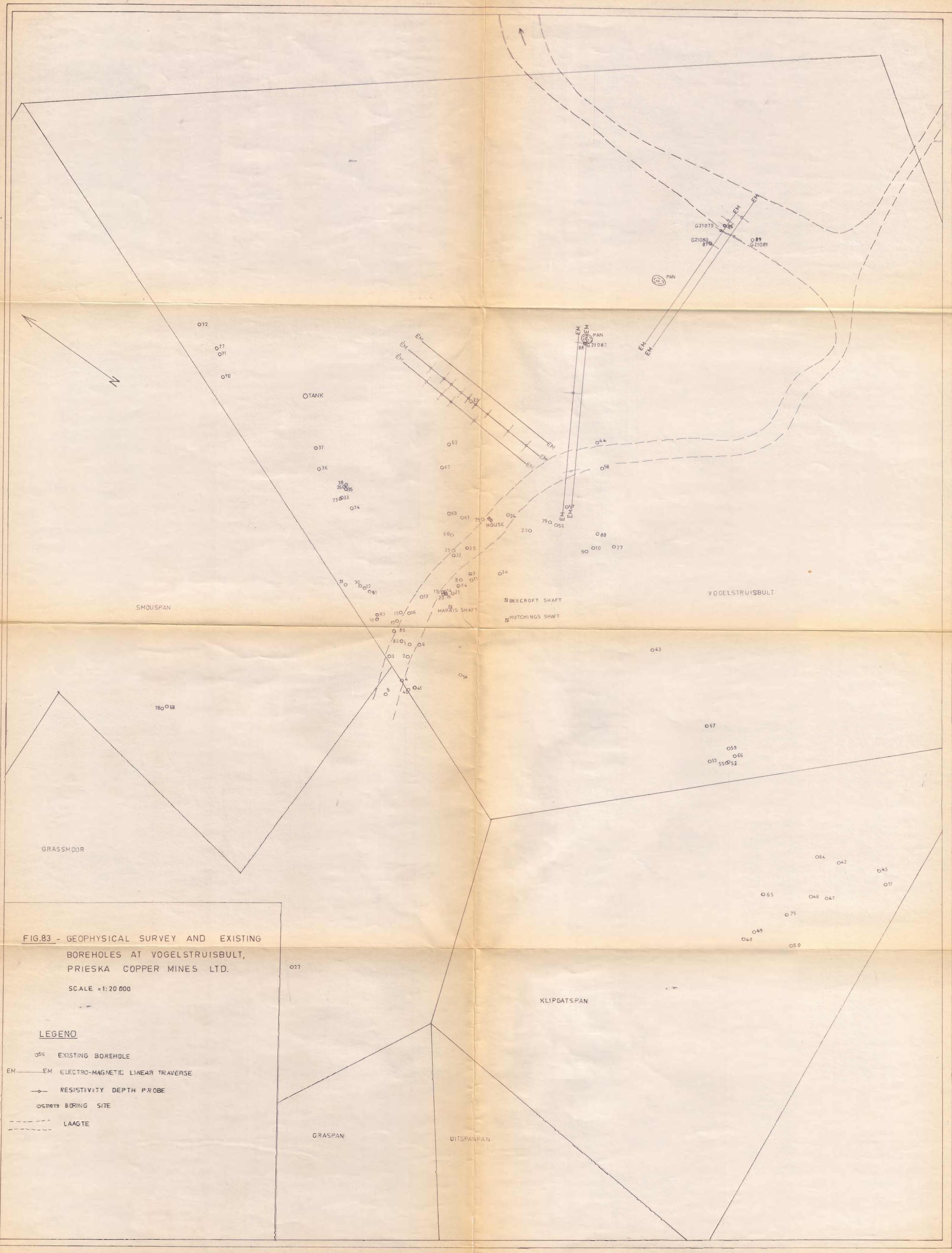
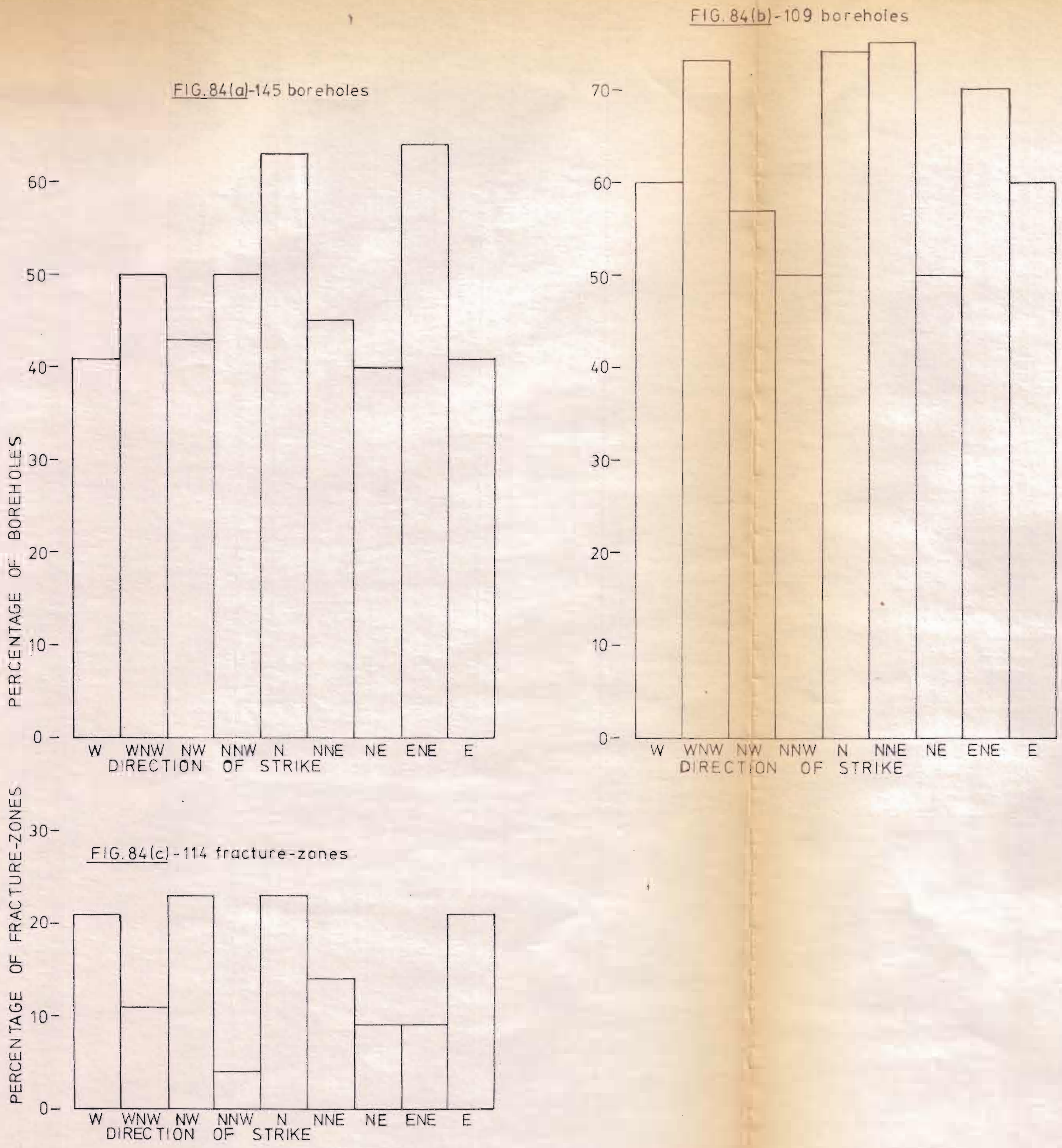


FIG.83 - GEOPHYSICAL SURVEY AND EXISTING BOREHOLES AT VOGELSTRUISBULT, PRIESKA COPPER MINES LTD.

SCALE = 1:20 000



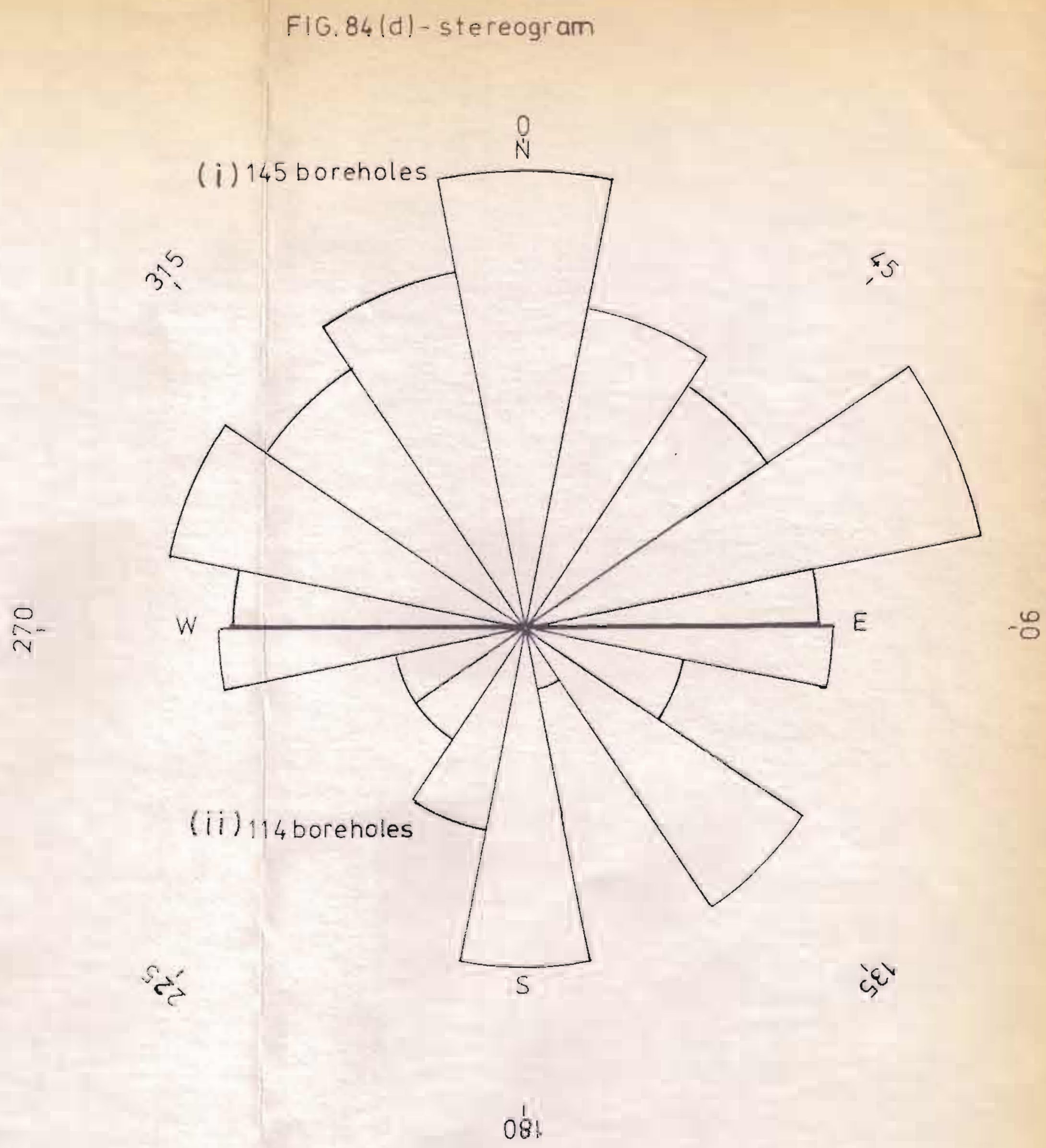


FIG.84(d) - STEREOGRAM OF DIRECTIONS OF STRIKE OF FRACTURE-ZONES WITH REFERENCE TO (i) PERCENTAGE OF SUCCESSFUL BOREHOLES; (ii) NUMBER OF FRACTURE-ZONES, N.W. CAPE PROVINCE.

FIG.84 - HISTOGRAMS OF THE DIRECTIONS OF STRIKE OF FRACTURE-ZONES WITH REFERENCE TO THE (a) PERCENTAGE OF SUCCESSFUL BOREHOLES; (b) PERCENTAGE OF SUCCESS AFTER ELIMINATING SHALLOW BOREHOLES; (c) NUMBER OF FRACTURE-ZONES, N.W. CAPE PROVINCE.

An example of the curvature in the strike of a fracture-zone is given in Fig. 85. This zone on the farm Hellem, Kenhardt District, was mapped after twelve unsuccessful boreholes had been drilled to depths of 21 - 155 m; and the thirteenth borehole, 20 m north of the fracture-zone yielded a useful supply. More than 150 electrical resistivity depth probes, five circular electromagnetic set-ups, and a large number of magnetic readings had been done on the farm by several geologists, including Vegter (unpublished report) and the author. From the resistivity depth probes were seen that weathering in the coarsely-crystalline Grey Gneiss was shallow over the whole farm. A maximum depth of weathering of 36 m was measured, whereas the ground-water rest level was between 48 and 60 m. Along the fracture-zone the weathering was also shallow, and the electro-magnetic readings did not show a continuous conducting zone. Only at Set-up III did the fracture show a conducting zone, but not further to the east. The geophysical surveys were, therefore, of very doubtful value, and the selection of the only producing borehole on this farm, depended on the interpretation of the geological and hydrological significance of the fracture-zone and of the probable dip of the curving fracture.

10.2.3 LINEAR STRUCTURES AS AQUIFERS

Because of the general narrow permeable zone associated with linear structures, they cannot store a large supply of water.

Their importance as aquifers lies in the free movement of ground-water along them. Numerous joints and small openings in weathered and semi-weathered country rock are cut by the fracture-zone, and ground-water is drawn from an area many times the volume of the permeable zone in the fracture. The yield from a fracture-zone is therefore large compared to its storage capacity, because the ground-water is constantly being replenished from the surrounding formations.

10.2.4 DEPTH OF FRACTURES

The depth to which fracture-zones are permeable, probably vary between wide limits. Strong supplies of ground-water of 5 to 16 m^3/h have been struck between depths of 90 to 135 m. On the other hand near Kakamas, in Kenhardt District, a strong supply was struck at a depth of 9 m along a prominent quartz-filled fracture-zone. As a general rule the more prominent structures, which can be traced for long distances along their strike, are proportionally open-jointed to a greater depth than short structures, or structures which are not well-developed.

10.2.5 STATISTICS

From a total of 157 boreholes drilled along fracture-zones in the granite and gneiss in the North-western Cape Province, a total of 74 (47 per cent) was successful. If the number of boreholes which were stopped before the ground-water rest level was reached, is subtracted, 51 per cent of the rest was successful.

Because the fracture-zones are limited in width, and often have an unknown dip, an appreciable percentage of the boreholes passed through the zone into solid rock at a depth shallower than the rest level. According to the records, this was the case in 28 boreholes which were total failures. If these boreholes are eliminated from the above calculations, 63 per cent of the boreholes drilled in fracture-zones to a greater depth than the rest level in this area, were successful. This figure is appreciably higher than the average for boreholes in the Grey Gneiss in the areas with the highest average annual rainfall. A cumulative graph was drawn of 123 boreholes drilled in fracture-zones showing the yield as a function of the percentage of the number of boreholes (Fig. 86). The high percentage of 17,1 boreholes yielding more than 4,55 m^3/h, is remarkable for this area, and illustrates the permeability of the fracture-zones.

The depths at which water was struck are illustrated in Figs. 87 (a) and (b). Of the total number of boreholes 28,8 per cent yielded water deeper than 75 m, and 12,8 per cent deeper than 105 m. The equivalent figures for successful boreholes were 22,5 and 7,5 per cent respectively. These figures are not particularly high compared to the results described in Chapters 8.2.2.2 to 8.2.2.8. Of the successful boreholes 75 per cent yielded water between 15 and 75 m.

The rest levels in 81,9 per cent of all the boreholes, and in 84,9 per cent of the successful boreholes, were shallower than

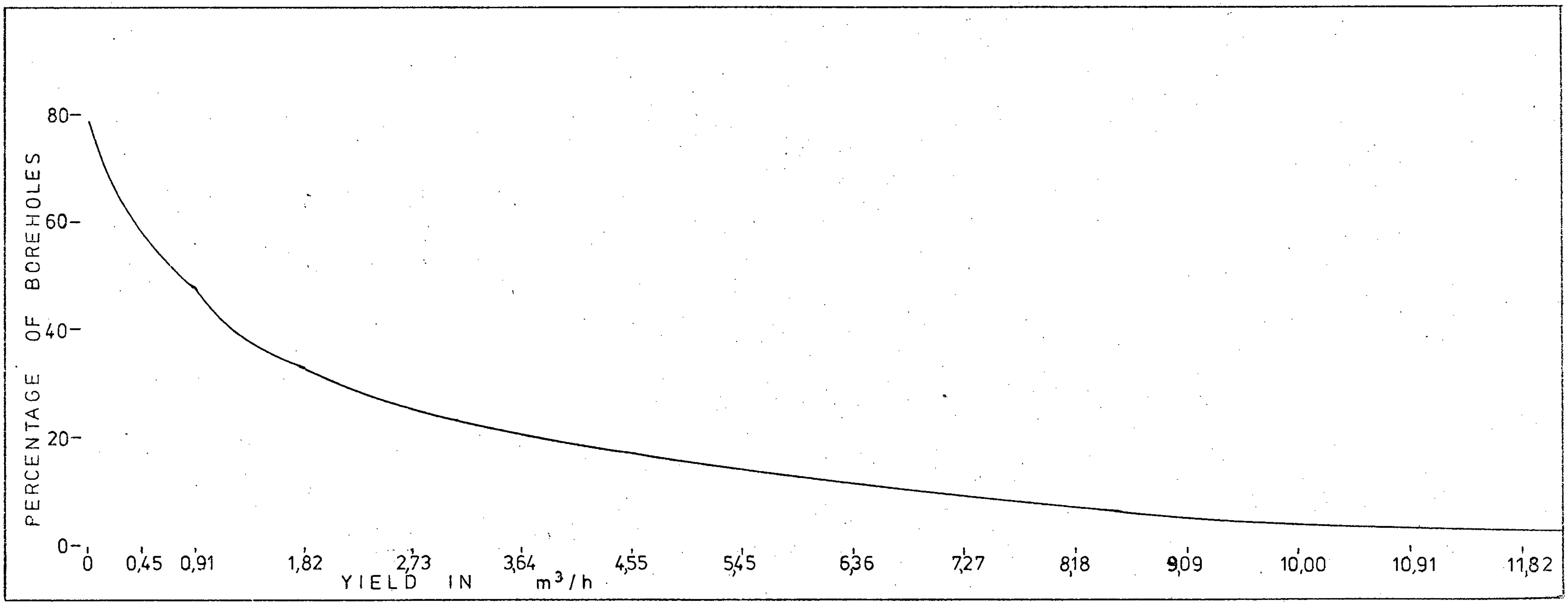


FIG.86 - CUMULATIVE GRAPH OF YIELD AS A FUNCTION OF THE PERCENTAGE OF THE NUMBER OF BOREHOLES, FRACTURE-ZONES, N.W.CAPE PROVINCE.

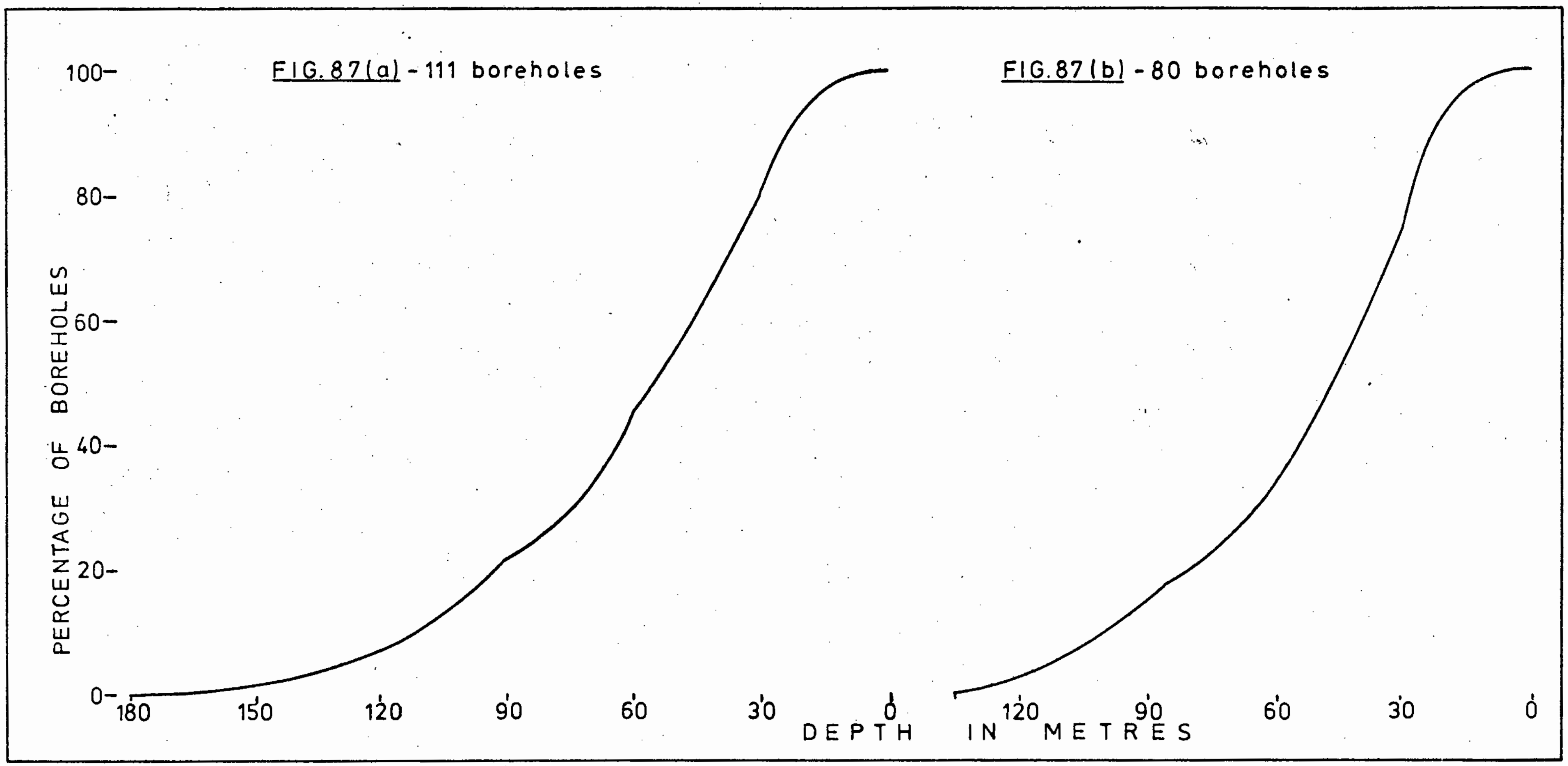


FIG. 87-CUMULATIVE GRAPHS OF THE DEPTH AT WHICH WATER WAS STRUCK AS A FUNCTION OF THE PERCENTAGE OF THE (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; FRACTURE-ZONES, N.W. CAPE PROVINCE.

60 m (Fig. 88(a) and (b)).

Because of the high permeability of fracture-zones it is not surprising that in 66,7 per cent of the boreholes water was struck within 12 m of the ground-water rest level (Fig. 89 (a) and (b)). The permeable zone is, however, usually narrow, and boreholes sometimes traverse an appreciable thickness of impermeable rock before this zone is struck. The result was that water was struck in boreholes down to 135 m below the rest level. In the case of successful boreholes, where it was expected that fracture-zones would be more permeable, the greatest difference was 65 m.

10.2.6 CONCLUSIONS

(i) Due to a universal covering of soil or calcrete, very few fracture-zones have been located in the North-western Transvaal. They are usually cemented by secondary quartz to form impervious barriers to the movement of ground-water.

(ii) In the North-western Cape Province fracture-zones can be recognised from the surface by a number of indications. They are numerous, and sometimes topographically prominent over long distances. Secondary quartz is always present, and mylonite, breccia, epidote and calcite are frequently found along them.

(iii) Geophysical methods to trace fracture-zones and to determine the probability of striking successful supplies along them, have been developed. These methods are not always successful, but have been efficient on several dry farms.

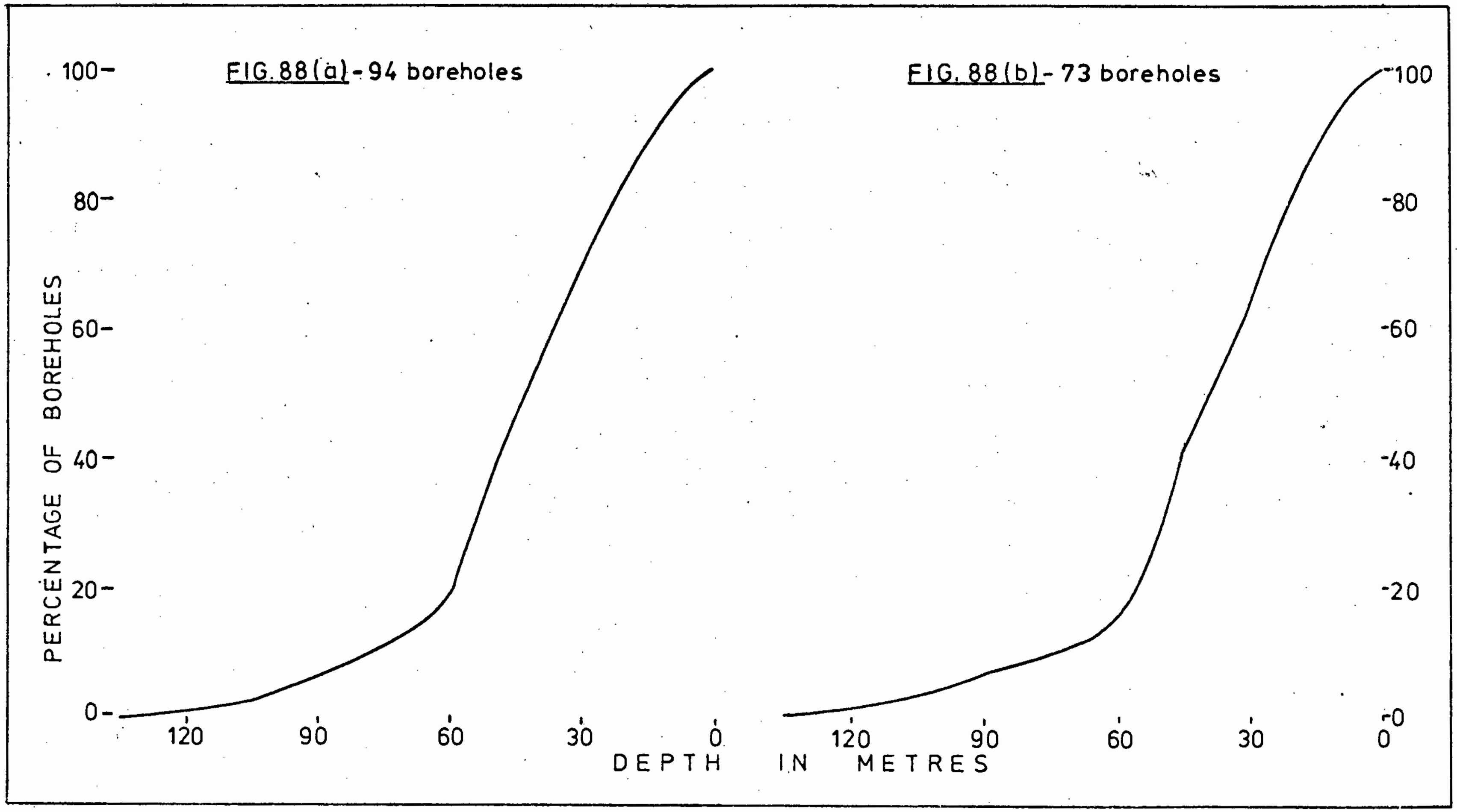


FIG.88 - CUMULATIVE GRAPHS OF THE REST LEVEL AS A FUNCTION OF THE (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; FRACTURE-ZONES, N.W. CAPE PROVINCE.

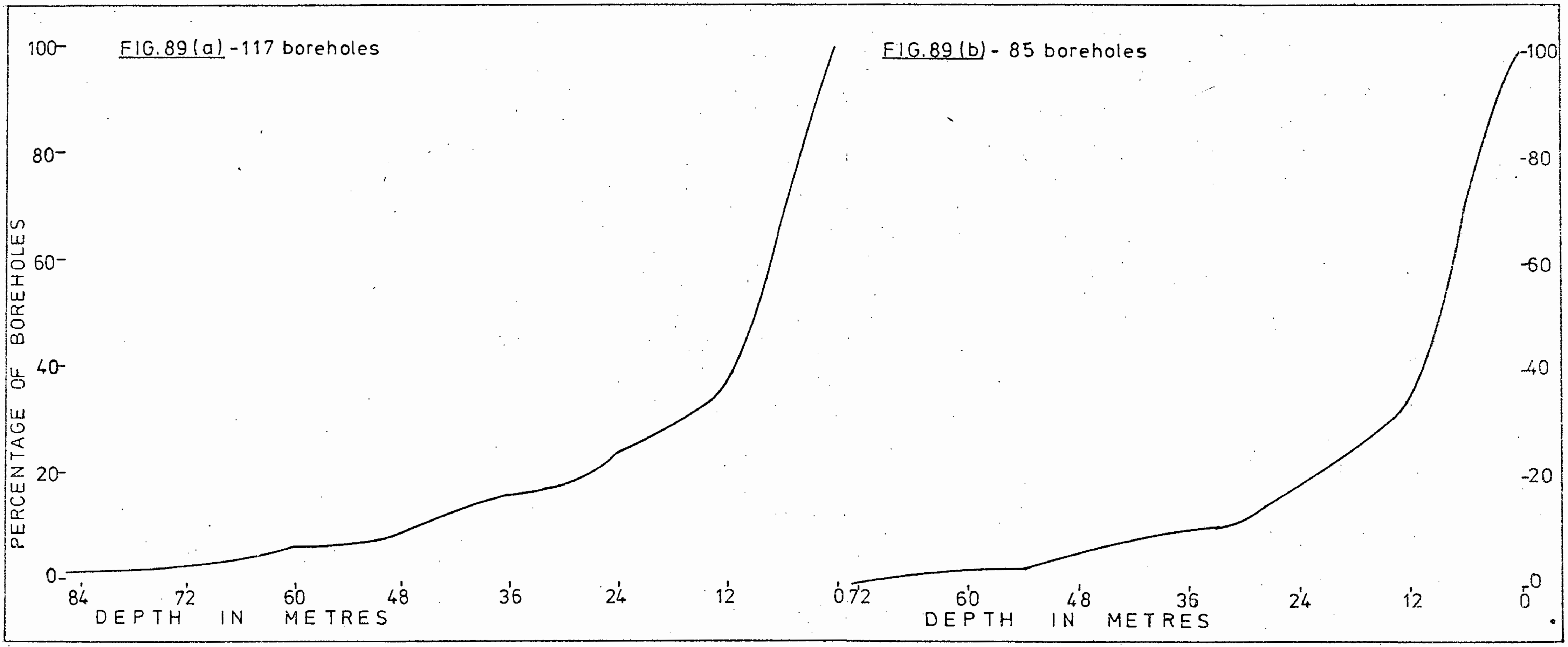


FIG. 89 - CUMULATIVE GRAPHS OF THE DEPTH AT WHICH WATER WAS STRUCK BELOW THE REST LEVEL AS A FUNCTION OF THE PERCENTAGE OF THE (a) TOTAL NUMBER OF BOREHOLES; (b) SUCCESSFUL BOREHOLES; FRACTURE-ZONES, N.W. CAPE PROVINCE.

(iv) Fracture-zones strike in many different directions, and the percentage of successful boreholes did not vary much from one direction to another. No conclusion about the relative ages of the fracture-zones could be reached from the strike-directions. Some of the zones curve or meander in strike and dip.

(v) The depth to which fracture-zones are permeable vary between wide limits. Water was struck between 9 and 135 m, but sheared granite have been drilled from a fracture-zone down to a depth of 185 m.

(vi) The yields of boreholes and the percentage of successful boreholes, are higher along fracture-zones than in the rest of the boreholes in the Grey Gneiss. Due to the narrow permeable zone, borehole sites have to be selected with care.

(vii) The depth at which water was struck in fracture-zones does not differ much from that in the rest of the boreholes in the Grey Gneiss. The zones are probably permeable to approximately the same depth as joints and cracks in the granite and gneiss.

11. RECHARGE OF GROUND-WATER

11.1 TRANSVAAL

No study has been made in this area of the percentage of rainfall which percolates down to recharge the ground-water reservoir, but this percentage must be small, especially in the granite of the Archaean Complex, and in the Swaziland System. Although outflow from this area is prabably small, transpiration and evaporation must be very high. There probably exists a balance between the precipitation and the cover of vegetation, which accounts for evapotranspiration of the bulk of the rainfall and the loss of flow in the perennial rivers while they traverse the area. High evaporation and transpiration in this area are due to the following conditions:

(a) An average of 78 per cent of the rain falls during the five summer months of November to March. Average evaporation from open water surfaces during the summer half-year is more than 1 250 mm (Dept. of Water Affairs, 1958), and the average rainfall is 420 mm. Although rain falls as thunder storms the intensity of rainfall is not high. During January, when intensity is at a peak, the average maximum precipitation during 24 hours is 13,7 mm, and the average for the whole month just over 90 mm. Abnormally high or low rainfall is also rarer than in most other parts of the Republic of South Africa (Climate of South Africa, 1960);

the average deviation from the annual rainfall being less than 20 per cent. Due to this low intensity of rainfall, the lack of relief, and the thick plant cover, run-off to laagtes, dams or pans is low and evapo-transpiration high.

(b) The growing season for plants and trees is from October to April in this area. The bulk of the rain therefore falls during the season of most active growth when transpiration is at a peak. The whole area is relatively thickly covered by trees, bush and grass. The depth of the ground-water rest level below the surface was usually so great that ample time was available for tree and grass roots to transpirate almost all of the infiltrating water before it reached the ground-water reservoir. Roots from a 3 m high <u>acacia heterocantha</u> were found at a depth of 24 m in joints in granite in a well. After precipitation a large portion of the phraetic water may be required to recharge the field capacity (due to the deep dewatering by plant roots) before water can percolate down to the ground-water rest level (Tolman, 1937).

(c) Due to the lack of relief, and the depth of soil and calcrete over the whole area, there is hardly any surface flow. This means that the rainwater does not flow into basins or dams in sufficient volume to augment infiltration by a significant figure.

(d) The clayey texture of the soil over large areas, and the general lack of linear features at the surface retard infiltration of ground-water, and thus promote higher evaporation and transpiration. In a large number of boreholes a layer of clay or clayey soil of 3 to 15 m in thickness was found from depths of 3 to 6 m below the surface, forming an effective aquiclude to the percolation of ground-water, and therefore, promoting evapotranspiration.

The result of high discharge of ground-water and low recharge was seen in the drying up or weakening of boreholes. In 45 out of a total of 451 boreholes the yield had decreased by at least 50 per cent, and several boreholes had dried up completely. The decrease in yield was usually accompanied by a lowering of the ground-water rest level. This figure of 10 per cent of the boreholes in which the yield had been drastically reduced, is probably only a fraction of the true percentage, due to the fact that very few boreholes had been used to their full capacity previous to 1950, and a large number of records of the original yield had been destroyed or forgotten.

On Noord Brabant 485 two boreholes in a laagte yielded 1,02 and 2,73 m^3/h from depths of 43,3 and 67 m. The yield from these boreholes decreased to 0,23 and 0,45 m^3/h. After deepening the boreholes to 71,6 and 80,7 m the yields of both boreholes increased to 0,91 m^3/h. These yields had again weakened to 0,45 m^3/h by 1957.

In Table IV ground-water rest levels in fifteen boreholes from this area have been tabulated. It is interesting to note the rise and fall of the rest level in hole No. 52830 on Laastepoort 840, according to the seasons. This borehole is affected by rainfall and the flow in the Marico River. The general trend is, however, a lowering of the rest level, which means that the recharge at the boreholes must be less than the discharge.

Because there are no towns or villages in this area, and water is used only for domestic purposes on farms, and for stock watering, consumption was relatively low. It has been calculated that consumption was slightly more than 5 000 m^3 per day during summer, and slightly less than this figure in winter. The average annual consumption was, therefore approximately 1,8 x $10^6 m^3$.

The average annual precipitation over the same area was more than 11 x 10^8 m^3. If it is assumed that only 0,5 per cent of the rainfall percolates down to the ground-water reservoir (Compare the figures of Enslin (1949) and Theron (1947) in more favourable areas), infiltration would still be more than three times the consumption. The following possible explanations for these figures are discussed:

(a) The infiltration is almost negligible, being less than 0,15 per cent of the annual precipitation. This assumption is hard to believe for an area with such a consistent rainfall, and the periodic rise in rest level, e.g. of 6 to 9 m in Bh. No. 52830

TABLE IV. GROUND-WATER REST LEVELS MEASURED DURING THE YEARS 1925 TO 1957 IN BOREHOLES DRILLED IN THE ARCHAEAN FORMATIONS IN RUSTENBURG DISTRICT, NORTH-WESTERN TRANSVAAL.

Borehole number	Name & Number of Farm	Year in which rest level was measured										
		1925	1932	1939	1940	1945	1948	1951	1953	1954	1955	1957
		Month of measurement, and depth in m										
44298	Blinkwater 628							Oct. 41,1		Jan. 41,1		
26324	Doornlaagte 110				May 65,3				Dec. 66,8			
57642	Doornlaagte 110										Apr. 54,9	
											May 51,2	
55053	Dwaalboom 464									Jun. 48,8		
										Jul. 51,5		
Private	Dwaalboom 464					Oct. 51,8				Mar. 55.5		
Private	Honingvlei 63				Aug. 45,7				Dec. 44,8			
49569	Klipdrift 842								Jan. 33,5	Jan. 32,9		
50011	Klipdrift 842								Jan. 34,2	Jan. 33,9		
Private	Kwaggasvlei 775						Feb. 85,4			Jan. 83,3		
44212	Laastepoort 840							Aug. 30,5	Dec. 32,9			
52830	Laastepoort 840								Oct. 32,0	Aug. 42,7	Mar. 33,5	Feb. 33,5
											Sep. 39,6	
10570	Noord Brabant 485	Nov. 51,8					Sep. 64,0			Oct. 67,1		
26699	Noord Brabant 485				Sep. 53,7		Sep. 73,2			Oct. 76,2		
25566	Rainpan			Nov. 21,3						Feb. 30,5		
16783	Verpoort		Mar. 57,0						Dec. 57,4			

on Laastepoort 840, and rises in three of the other boreholes in Table IV over periods of one to thirteen years.

(b) Ground-water is drained out of the area by subsurface flow at a higher rate than the annual consumption. This is a feasibility which can only be evaluated by absolute water level measurements over an extended period and in a large number of well-chosen boreholes. Such a study is at present impracticable. The nature of the soil and the low relief makes this assumption appear to be far-fetched.

(c) Ground-water in a borehole is drawn from a relatively small area due to the low permeability of the formations, and dewatering is a strictly local phenomenon. This assumption is credible, and is confirmed by the high percentage of boreholes which remain productive over a long period, without appreciable lowering of the ground-water rest level. In Table IV can be seen that in 43 per cent of the boreholes the rest level had risen, remained the same, or had dropped by less than 0,3 m over periods which range from one to twenty one years.

The drying up or weakening of boreholes must, therefore, usually be due to dewatering of the aquifer in a very localised area, as a result of overpumping. By careful selection of borehole sites and the use of plastic piping to bring water to the points where it is required, no shortage of water for domestic use or stock-watering purposes, should occur in this area. No irrigation from boreholes can be recommended in this area.

11.2 CAPE PROVINCE

11.2.1 GENERAL

Although the rainfall in this area is much lower than in the Transvaal, conditions are more favourable for the infiltration of water to the ground-water rest level. In the eastern portion of the area, where surface limestone is found over large areas, the rainfall is higher, many outcrops of rock are found, and linear features crop out at the surface infiltration and percolation down to the ground-water rest level is appreciable. This was proved in Chapter 8 by the increase in the percentage of successful boreholes, and in the average yield of boreholes in the granite and gneiss with increase of rainfall.

In the sand-covered areas of the western portion of Kenhardt District, the eastern portion of Namaqualand District, and the northern portion of Calvinia District, the situation is entirely different. In these areas the rainfall is very low and infrequent, often with long periods of drought in between. Infiltration down to the rest level through the thick cover of sand, must therefore, be practically nil, except after exceptional rainfall, usually of very local extent. Much of the water being pumped from boreholes today, should probably be regarded as fossil water, which was stored underground during previous more rainy periods. The high percentage of total dissolved solids in many of the supplies of ground-water is an added argument in favour of this postulation. Due to the low recharge, as described in the experiments following, water levels have receded in several areas in which pumping takes place. On Witvlei, Prieska District, the water level in wells in the large laagte passing the house, receded from 6 to 18 m between 1954 and 1969. On Ebenezer, Prieska District, the owner stated that between 1941 and 1967 no run-off occurred which was high enough to fill the dams and pans on the farm to full capacity, and rest levels had receded by as much as 24 m.

11.2.2 TEST AREA AT MARYDALE

11.2.2.1 PURPOSE OF INVESTIGATION

Because very little information had previously been collected of the recharge of ground-water in semi-arid areas in the Republic of South Africa, in which the average annual rainfall is less than 200 mm, an effort was made to calculate the water balance of a typical area in the North-western Cape Province. Suitable sites for this type of calculation were hard to find, because a closed, or semi-closed catchment area was required, with a surface area large enough to make it representative of its environments. The site also had to be accessible by roads, the precipitation had to be measured with reasonable accuracy, and discharge had to be reasonably large and measurable.

Such a catchment area was found to the south of Marydale, south of the boreholes which were pumped for the supply of water to the village of Marydale. The catchment area behind the narrow poort of approximately 400 m in width, was 28 250 ha, or 282,5 km^2 in extent. The municipality of Marydale kept a record of the water pumped from their boreholes, and underground outflow through the poort could be calculated. Consumption on the farms in the catchment area could be calculated, and the surface flow through the poort was measured after completion of the dam, and estimated from available data for previous flows. Rainfall was measured at ten points in and near to the catchment area. However, continuous records for the whole period of investigations, were available from only three stations. Missing data were interpolated where possible. Pumping tests were done at the municipal boreholes, but due to several adverse factors, a final pumping test and evaluation planned for 1971-72, could not be satisfactorily concluded. The available data and calculations, however, give a fairly accurate evaluation of the water balance.

11.2.2.2 DESCRIPTION OF AREA, TOPOGRAPHY, AND VEGETATION

The catchment area lies between eastern longitudes 21°57' and 22°06', and southern latitudes 29°25' and 29°33', to the south and south-east of the village of Marydale, Prieska District. Quartzite of the Kaaien Series forms mountainous areas between broad, flat valleys in the eastern and north-western portions of the catchment, while granitised sediments of the Marydale Series crop out in the south and south-west. The topographical relief is not high, being approximately 150 m between 1 052 and 1 202 m above m.s.l. The slopes of the quartzite ridges are steep, whereas the granitised sediments form hills with much gentler slopes, and more rounded contours. The catchment area and drainage channels are shown on the accompanying map of Fig. 90. The gradient in the large broad valleys is very low, so that surface flow was slow. Only sudden and large downpours caused surface flow of water past the municipal boreholes. Small earthen dams on farms in the valleys, retarded the flow and aided infiltration.

The whole catchment was sparsely covered by xerophytic plants and grass, with single low-growing witgat (boscia albitrunca) and swarthaak (acacia heterocantha) trees. Isolated succulents e.g. aloe dichotoma and aloe hereroensis were found along the slopes of ridges. In the valleys thickets of driedoring (rhigozum trichotonum) were found, and to a lesser extent kriedoring (lyceum-varieties), wolfdoring (phaeoptilum spinosum), brosdoring (phaeoptilum-variety), ganna (salsola-varieties), and karoobos (pentzia-varieties). Most of the grass was varieties of Boesmangrass(aristida-varieties), and annuals abounded in winter after good rainfall. The farmers in the catchment area planted lucerne, prickly pear, fruit trees, pines, eucalyptus trees, and karree (rhus lancea). The relief of the catchment area is shown in Fig. 90.

11.2.2.3 GEOLOGY OF THE CATCHMENT AREA

The catchment area lies on the Kheis System into which the Grey Gneiss had been intruded. The gneiss occupies the low-lying areas, and outcrops are usually seen only on the slopes of ridges and kopjes in the central portion, and in rounded undulating hills in the western portion. The Marydale Series consists of granitised and gneissose sediments, various granulites , amphibolite, basic lava which was sometimes amygdaloidal, and ferruginous quartzite. The Kaaien Series has a coarse basal conglomerate with large elongated boulders and pebbles in the south-western portion of the area. This is followed by hard resistant quartzite which forms most of the ridges. Towards the north-west the quartzitic sediments changes to quartz-schist or quartz-sericite-schist. The whole succession is intensely folded, generally with high dips, which are sometimes vertical or overfolded. The most prominent fold-axes strike approximately north-west, but there are at least three other directions of folding, of which the north-south direction is the youngest, younger than the prominent north-west folding. Shearing is often seen in the quartzite, and quartz veins were found in several places, usually with the same north-west strike as the folding. A few minor faults were found to be striking in the same direction on the southern edge of the area, and a very prominent shear-zone filled with secondary quartz crossed the south-western portion of the area. Its strike is also north-west to WNW. A prominent fault filled by mylonite, breccia, and secondary quartz was mapped in the eastern portion of the catchment area. This fault, which has a NNW strike, probably has a large throw to the west, and traverses the whole length of the catchment area. A geological map of the catchment area is shown in Fig. 91.

11.2.2.4 RAINFALL

Rain falls during summer, generally as sudden thunderstorms of short duration. These storms were often of such local extent that precipitation occurred in only a small portion of the catchment area. On the plan in Fig 90 eight rain gauging stations, R1 to R8, are shown. Three stations operated throughout the period of measurement from 1962 to 1972, whereas the others were in use for shorter periods. A few examples of the differences in precipitation at the different gauging stations are the following;

(i) On the 21st of October 1969 the following precipitations were recorded: No rain at R1, R2, R5, R7, and R8; 15,2 mm at R6; 19,0 mm at R3; and 20,3 mm at R4.

(ii) On the 27th of March 1969 no rain fell at R1; 1,0 mm at R2; 8,9 mm at R6; 20,3 mm at R5; 25,4 mm at R7; and 45,7 mm at R8.

(iii) On the fourth of March 1968 precipitation at the above gauging stations varied between 5,0 and 44,4 mm.

(iv) During 1968 precipitation for the full year varied between 186,9 and 300,3 mm at the eight gauging stations.

Isohyets for the period from the first of January 1968 to the 31st of October 1969 is shown in Fig. 90. During this period the rainfall records were checked monthly by the author, and it was reliable enough to be used as a basis for calculations.

Total annual precipitation for the gauging stations R1, R2, R3 and R4 during the ten-year period 1962 to 1971 is given in Table V. The average for the four stations during this period was 188,5 mm. This compares well with the normal of 185,7 mm calculated by the Weather Bureau (Climate of South Africa, 1955) for the village of Marydale. From Table V the extreme variability of the rainfall can be seen. At Marydale village it was 44,5 per cent of normal in 1962, and 185,7 per cent of normal during the next year.

A large percentage of the precipitation was in the form of short, light showers which caused no surface flow. Although such factors as temperature, season of the year, topography, plant cover, aridity of the soil and its field capacity, previous downpours, and other factors are of importance in calculating the volume of precipitation which will cause surface flow, a minimum precipitation of 20 mm in 24 hours is regarded as the lower limit of rainfall which will cause enough surface flow for concentration in laagtes and dams, and allow water to infiltrate to an

TABLE V. ANNUAL RAINFALL IN MM AT FOUR GAUGING STATIONS IN THE TEST AREA NEAR MARYDALE, NORTH-WESTERN CAPE PROVINCE.

Year	R1 Marydale	R2 Brakboschpoort	R3 Kareeboomput	R4 Rooidam
1962	82,6	92,0	107,9	
1963	344,2	324,2	348,9	
1964	152,3	179,0	151,0	
1965	127,0	132,6	95,4	98,3
1966	113,0	148,0	147,8	121,9
1967	208,2	263,2	333,7	198,1
1968	211,0	190,4	186,9	300,3
1969	131,0	132,7	181,6	209,2
1970	224,6	170,3	225,4	182,5
1971	208,6	194,1	284,4	183,5
Average	180,3	182,7	206,3	184,8

Average for the four gauging stations = 188,5 mm appreciable depth into the soil. The percentage of the rainfall which exceeded 20 mm in 24 hours for the years 1962 to 1969 at the gauging stations mentioned above, is given in Table VI. It is interesting that in the years in which the rainfall was well below normal (1962, 1965, and 1966) the percentage of the rainfall over 20 mm was low, except for R4, but the records at this gauging station were sometimes not reliable. In 1962 no precipitation reached a figure of 20 mm in 24 hours, and it is almost certain that no infiltration to the ground-water rest level took place.

11.2.2.5 GROUND-WATER REST LEVELS

Ground-water rest levels were measured regularly in the catchment area between Marydale village and the municipal boreholes, in more than 30 boreholes and wells, some of them since 1964. Automatic water level recorders were installed in three boreholes drilled especially for this purpose in 1964 near the municipal boreholes. At a later stage recorders were also installed at Rooidam and Brakboschpoort, and for measuring surface flow. Collar levels of the boreholes and wells were surveyed by theodolite, except for some of the more distant boreholes on Neeldale, Witkop and Brakboschpoort, which were levelled by repeated barometric readings. Contours for the rise and fall of the ground-water rest level are shown in Fig. 92. These are smoothed contours for borehole G19070 and the flow over the V-notch in the furrow from the perennial spring below the dam wall. The

TABLE VI. PERCENTAGE OF THE ANNUAL RAINFALL WHICH EXCEEDS 20 MM IN 24 HOURS, TEST AREA NEAR MARYDALE, NORTH-WESTERN CAPE PROVINCE.

Year	R1	R2	R3	R4	R5	R6	R7	R8
1962	0	0						
1963	52	55						
1964	53	64	58					
1965	54	42	24	68				
1966	23	52	48	95				
1967	45	62	78	84				
1968	63	78	63	88	60	59	67	69
1969	67	63	61	61	80	66	89	71

ONS OF BOREHOLE NO. G19070, FLOW OVER V-NOTCH BELOW PERENNIAL SPRING, AND THE RAINFALL,
PROVINCE.

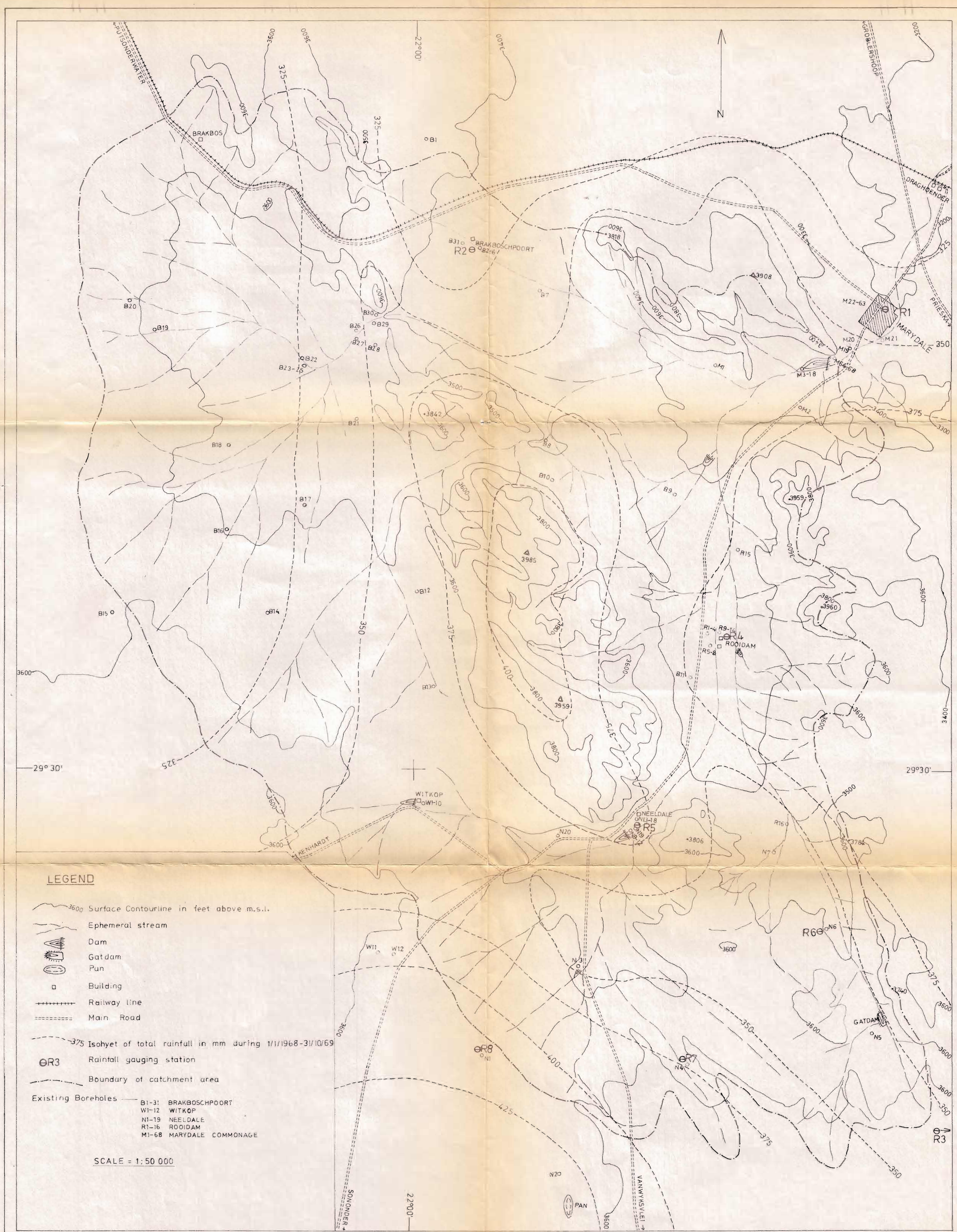


FIG. 90 - PLAN OF MARYDALE TEST AREA WITH SURFACE CONTOUR LINES, ISOHYETS, BOUNDARY OF CATCHMENT AREA, RAIN GAUGING STATIONS, AND EXISTING BOREHOLES AND DAMS; PRIESKA DISTRICT, N.W. CAPE PROVINCE.

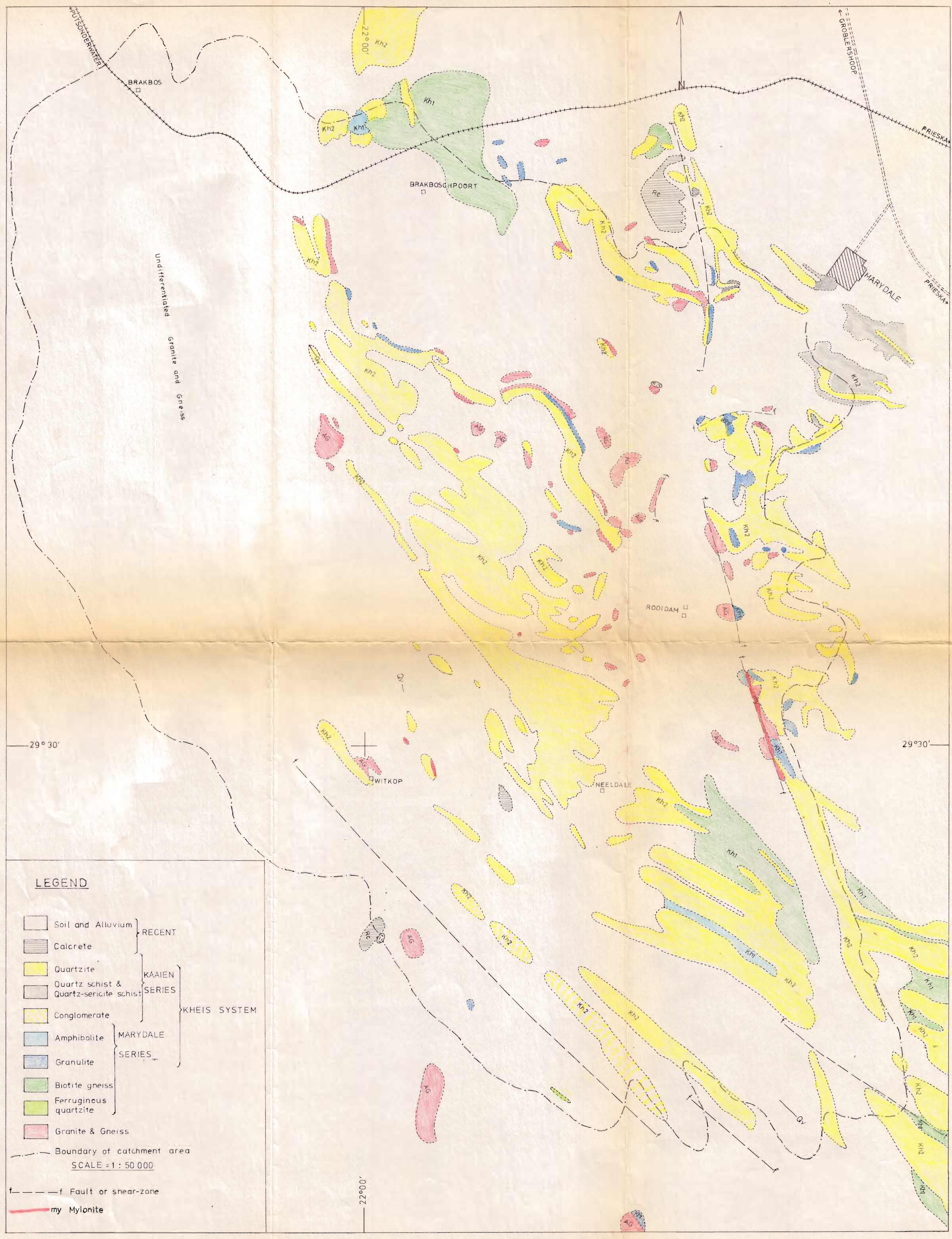


FIG. 91 - GEOLOGICAL MAP OF MARYDALE TEST AREA AND BOUNDARY OF CATCHMENT, MARYDALE COMMONAGE, N.W. CAPE PROVINCE.

FIG. 92 - GRAPHS OF WATER-LEVEL FLUCTUATIONS OF BOREHOLE NO. G19070, FLOW OVER V-NOTCH BELOW PERENNIAL SPRING, AND THE RAINFALL, MARYDALE COMMONAGE, N.W.CAPE PROVINCE.

FIG. 93 - PLAN OF POORT AT MUNICIPAL BOREHOLES AND DAM WITH ROCK OUTCROPS, SURFACE CONTOURS, AND CONTOURS OF ROCK FLOOR BENEATH THE ALLUVIUM, MARYDALE COMMONAGE, N.W.CAPE PROVINCE.

FIG. 94 - LONGITUDINAL SECTION THROUGH DAM BASIN AND POORT TO SHOW THE GRADIENT IN THE GROUND-WATER REST LEVEL AND THE DEPTH TO SOLID ROCK; MARYDALE COMMONAGE, N.W. CAPE PROVINCE.

rainfall figures from the nearest gauging station (R1) are shown for comparison. The spring dried up after the Marydale municipal pumping scheme had been in operation for approximately two and a half years, but started flowing again after a good rainy season. From Fig. 92 can be seen that the flow stopped for a brief period of 20 days in December 1966, and for a longer period in December 1967 to February 1968. After September 1968 no flow was recorded, except after heavy rain, due to a concrete wall that was built across the furrow to dam the water.

11.2.2.6 GRADIENT OF THE GROUND-WATER REST LEVEL

Water levels were measured relative to a datum level at the dam wall in 28 wells and boreholes in the poort between the catchment of the dam and the village of Marydale (Fig. 93). The measuring points covered both a longitudinal section and a cross-section. The water levels are very nearly horizontal normal to the poort, but have a decided gradient towards the east, viz. in the direction of outflow of the catchment. A longitudinal section in the poort to illustrate the gradient in the water level, is shown in Fig. 94. The average gradient through the poort was 0,00635. In the narrowest portion of the poort, where it is 700 m between outcrops of quartzite of the Kaaien Series, the gradient was 0,00700, and at the municipal boreholes where the laagte started to broaden above the poort, it was 0,00600. From approximately 300 m above the dam wall the gradient flattened out to 0,00107

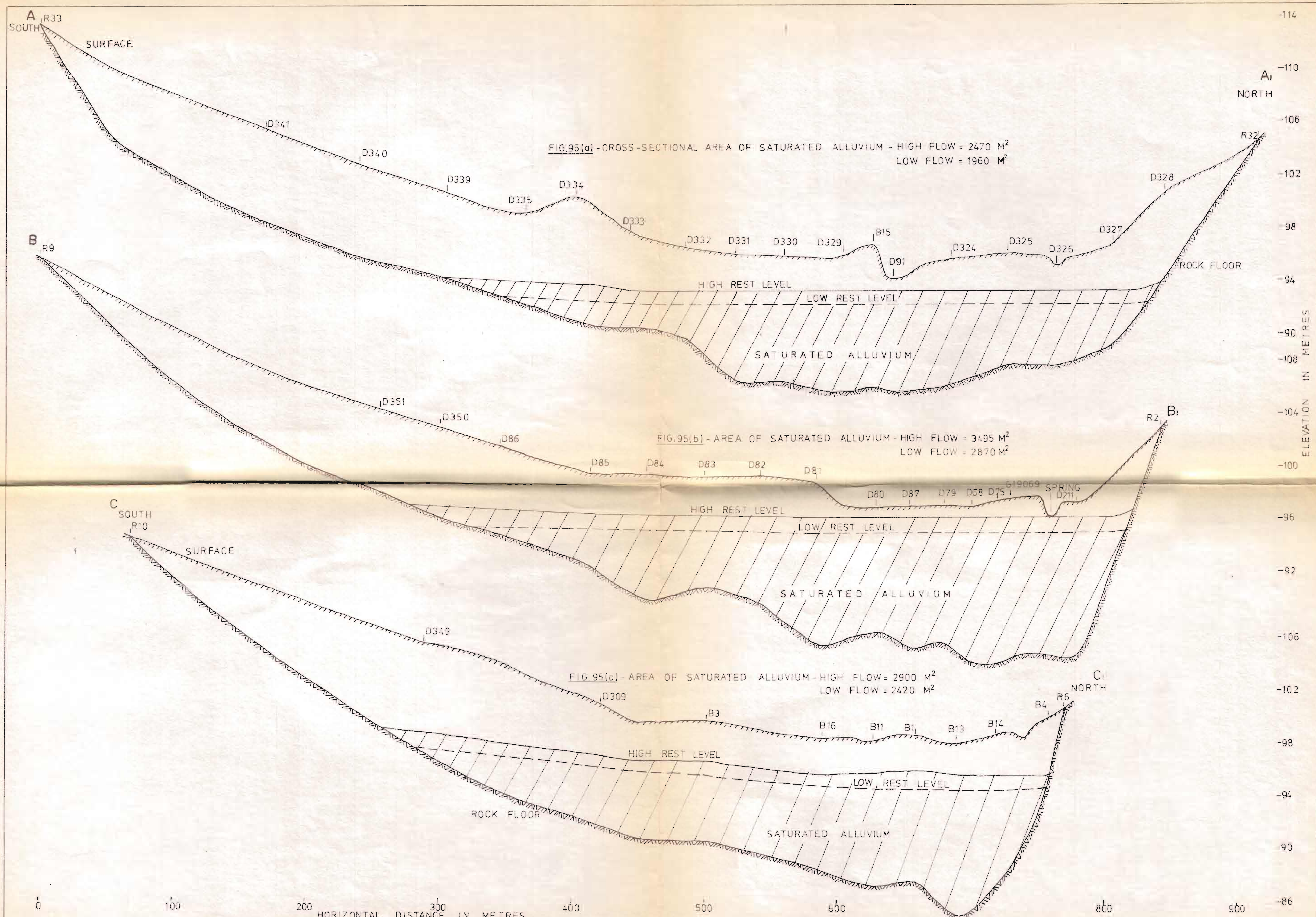


FIG.95 - CROSS-SECTIONS ACROSS POORT, WITH GROUND-WATER REST LEVELS AT HIGH AND LOW FLOW, AND AREAS OF SATURATED ALLUVIUM, MARYDALE COMMONAGE, N.W. CAPE PROVINCE.

for the next 1,8 to 2 km. Although the valley broadens considerably, this sudden change in gradient must partly be due to more permeable alluvium. From borehole B8 (Fig. 93) to the next borehole towards the north-west along the tributary laagte, the gradient was again 0,0031, and along the laagte to Rooidam, approximately 6 km to the south-west, it was 0,0024. Between Rooidam and Neeldale the laagte narrows again, and the gradient increased to 0,0042. Between Neeldale and Witkop it flattened out again to 0,00156. Along the tributary laagte from borehole B8 to the boreholes in the poort north of Brakboschpoort, the gradient was higher than the average along the main laagte viz. 0,00425. The gradient therefore, increased with narrowing of the valley , and with decrease of the permeability of the alluvium. Unfortunately, pumping tests could only be carried out at the municipal boreholes, so that the permeability at other points could not be determined.

11.2.2.7 THICKNESS OF ALLUVIUM

The alluvium consisted of soil, clay, calcrete, sand and gravel which possessed relatively high permeability. In the poort the upper 1 to 2 m was more clayey, and therefore, less permeable than the underlying layers. The thickness of alluvium on the floor of Kheis System sediments and Grey Gneiss, was determined by geophysical surveys in the catchment area, and in the poort between the municipal boreholes and Marydale village.

Electrical resistivity depth probes were done, and the results calculated empirically. A total of more than 400 depth probes were measured, most of them in the poort and the dam basin above the poort. In some cases of doubt, more than one depth probe was done at one site, setting out the electrodes in different directions. At existing boreholes the interpreted depth of alluvium was compared to the borehole record. In most cases the interpreted depth differed from the recorded depth by less than ten per cent.

The alluvium in the poort was up to 14 m thick, with a cross-sectional area at its narrowest point of more than 4 000 m^2. At Rooidam and Neeldale the alluvium was approximately 33 m thick. The ground-water rest level was between 1 and 3 m from the surface at the municipal boreholes, so that the maximum thickness of saturated alluvium was nearly 12 m. At Rooidam it was approximatly 10 m, and at Neeldale nearly 9 m. At Brakboschpoort the saturated alluvium in the poort west of the house was 5,5 m thick.

The surface area of the saturated alluvium in the dam basin above the narrowest point of the poort, was approximately 2 300 ha and the volume was calculated as 105 x 10^6 m^3. Three cross-sections through the poort are given in Fig. 95. Section (c) is probably the most accurate because of the number of boreholes drilled along this section. The volume of saturated alluvium varied during the year according to fluctuations in rainfall and the ground-water rest level. The maximum and minimum during one year are shown in Fig. 95.

11.2.2.8 PUMPING TESTS

A pumping test was carried out in 1959 when the water supply scheme of the municipality of Marydale was planned in order to determine the permeability, storage and safe yield of the alluvium in the dam basin above the municipal borehole and the perennial spring. Water was pumped continuously for 65 hours at a rate which varied between 38,6 and 32,7 m^3/h. The yield and the water levels in the borehole and shallow wells were measured accurately at regular intervals throughout the test period. The water was pumped out into the spruit below the borehole. The flow of the perennial spring diminished gradually but it did not dry up. The water level was lowered by 4,7 m during the test. Steady state conditions had developed after approximately 33 to 38 hours after pumping started. Only small fluctuations in the yield and the water level were measured during the last 27 to 32 hours.

Twenty four hours after pumping had stopped the water level in the borehole had recovered to a level 0,38 m lower than the level before pumping started. After that recovery was very slow, and not before thirteen days after pumping stopped, had recovery in the borehole and wells been completed. The whole cross-section of the poort must have been dewatered for approximately 0,38 m, and after the cone of depression had been filled, it took thirteen days before equilibrium in the flow through the poort had been established.

In 1970 another pumping test was carried out in the municipal well, by making use of the municipal pumps. The water was pumped into the reservoir, and the yield determined by the meter readings, and calculated from the capacity of the reservoir and the water levels in it. The pumping rate varied between 27,3 and 30 m^3/h, causing a drawdown of just over 3 m in 7 hours. Unfortunately one of the pumps broke down after this time, and although the test was continued for a total time of 25 hours, fluctuating water levels due to fluctuating yields, made further calculations impossible. Because more holes and wells were available for observation than in 1959, useful results about the permeability at different depths below the surface could, however, be collected. It was found that the water in the boreholes was semi-confined by the clayey topsoil in the poort. Drawdown started in boreholes G19070 and G19071, which are more than 66 m from the pumped well, 30 minutes after pumping started. In the wells (1,3 to 1,9 m deep) at distances of 19 and 28 m from the pumped well, drawdown started after 60 and 120 minutes respectively.

A pumping test planned for 1971 at borehole B1, had to be abandoned for technical reasons.

11.2.2.9 FLUORESCEIN TEST

Another method for the determination of permeability in the alluvium was tried in March 1970, by the introduction of fluorescein into a well 28,4 m upstream of the municipal well. The municipality agreed to operate their pumps continuously at a constant rate for a full week. Pumping was started at 07h00 on 9/3/70, and fluorescein was introduced into the well 0,6 m below rest level at 08h50. The average gradient between this well and the pumped well was maintained at 0,070 - 0,073. Samples of the water from different points between the two wells, were regularly inspected and compared with standard samples. After 104 hours the first trace of fluorescein colouring was sampled 7,95 m from the point of introduction. Due to the stopping of the pumps, no measurements could be done after 110 hours, when the gradient between the two points changed.

11.2.2.10 PERMEABILITY AND SPECIFIC YIELD

Calculations of the permeability in the alluvium in the poort at the municipal borehole and well were made by means of the non-equilibrium formula of Theis as modified by Cooper and Jacob (1946) for a graphical solution on semi-log paper:

$$T = km = \frac{2,3\ Q}{4\pi \Delta s}\ \mathrm{m^2/day} \qquad \text{or} \qquad k = \frac{2,3\ Q}{4\pi m \Delta s}\ \mathrm{m/day}$$

where T = Transmissibility in m^2/day;

k = Permeability in m/day;

Q = Pumping rate in m^3/day;

Δs = Drawdown per log cycle in m;

m = Saturated thickness of aquifer in m.

And $$S = \frac{2,25\ T\ t_o}{r^2}$$

where T = The same as above;

t_o = Time intercept in days on the zero-drawdown axis;

r = The horizontal distance between the observation well and the pumped well in m;

S = Storage coefficient, which is equal to the specific yield for water table conditions.

These formulae are only valid for large t, usually more than 12 hours. On the other hand S must be determined before the recharge of the cone of depletion by natural subsurface flow becomes appreciable. The value for k derived in 1959 was 1,56 m/h. During the test of 1970 k varied between 2,56 m/h for the shallow wells and 8,78 m/h for the boreholes drilled through the alluvium into the floor rock. From the fluorescein test a value of k = 0,994 m/h was calculated, for the upper portion of the alluvium. These results were too widely divergent to deduce the correct permeability.

The storage coefficients calculated from the above data according to the formula given, ranged between 0,009 and 0,111.

During the pumping test in 1959 steady state conditions were reached. This means that the cone of depression must have reached across the whole width of the water-saturated alluvium in the poort, and the pumping rate was in equilibrium with the flow through the poort. The volume of water pumped out in unit time after steady state conditions were reached, equalled the underground flow through the poort. This volume was 33,4 m^3/h, or 292 000 m^3/year. The rest level was low at that time, so that the cross-section of saturated alluvium at the narrowest point in the poort was approximately 2 400 m^2. The value of k can then be calculated as k = 1,99 m/h. This value can be regarded as the nearest approximation to the permeability, and is a good average between the values derived from the pumping tests and the fluorescein test. For calculation purposes a value of k = 2,0 m/h was used. The value for storage was taken as a conservative four per cent.

11.2.2.11 UNDERGROUND FLOW THROUGH POORT

The underground flow through the poort was calculated by means of the formula of Dupuit (Butler, 1957):

$Q = kIA$, where
Q = total volume of flow in m^3/year
k = permeability in m/year
I = hydraulic gradient
A = cross-sectional area of saturated alluvium in m^2.

During the time of testing A varied between 2 902 and 2 422 m^2 at the narrowest point in the poort; I was an average of 0,0065; and k was taken as an average of 2,0 m/h. The average underground seepage or flow through the poort was therefore, 303 800 m^3/year, and for calculations a figure of 300 000 m^3/year was used.

This figure is considered to be reasonably accurate because it was calculated from formulae for which the limitations were reasonably well approached viz.

(i) an aquifer of semi-infinite horizontal extent,

(ii) the aquifer was semi-confined by a layer of clayey soil, and therefore, approached the conditions of a confined aquifer,

(iii) the pumping tests were of long enough duration to be able to make calculations by means of the non-equilibrium formula,

(iv) during the first test steady state conditions were approached as near as possible with the pumping equipment which was used.

Seepage also occurred at the surface below the dam wall. A furrow from the perennial spring was dug in hard calcrete. A V-notch with an automatic water level recorder was used to measure the flow of the spring, between May 1965 and August 1968, when the flow was cut off by a concrete wall. Outflow varied between a maximum of more than 8 000 m^3/month and nil for several consecutive months during this period. A graph of the flow is shown in Fig. 92.

11.2.2.12 SURFACE FLOW

After heavy rain, water flowed over the dam wall and through the poort past the village of Marydale. Between November 1964 and February 1970 surface flow passed the municipal boreholes on nine occasions, with a total time of flow of 189 hours, or nearly eight days. Because the dam wall was not repaired before the end of 1969 only the most recent of these flows, between 4/2/70 and 5/2/70 could be measured. Water flowed for 18 hours over the crest of the weir. This crest was 76,2 m long, and the peak head reached was 35,5 cm. A graph of the flow is shown in Fig. 96. The discharge was calculated from the formula for broad-crested weirs viz.

$Q = CLH^{\frac{3}{2}}$ cub. feet per second, where C = a constant (in the case of Marydale C = 3,09),

L = length of crest in feet,

H = head in feet.

Total flow over the crest was 363 600 m^3. From all available information which could be collected of previous flows, the total flow during the six years from 1964 to 1970 was estimated at between three and four million m^3.

11.2.2.13 DISCHARGE BY PUMPING

11.2.2.13.1 FARMERS

In the catchment area ground-water was used for domestic purposes, stock watering, and for irrigation on a small scale. A total of 42 windmills were used to pump out water for stock, mostly sheep and goats. According to the owners the average number of small stock units in ths area was 11 200. This stock consumed approximately 18 600 m^3 of water per year. Water for domestic use amounted to approximately 2 600 m^3 per year.

A total of 30 windmills yielded water for irrigation of small lands of lucerne, cereals, vegetables, fruit trees and ornamental

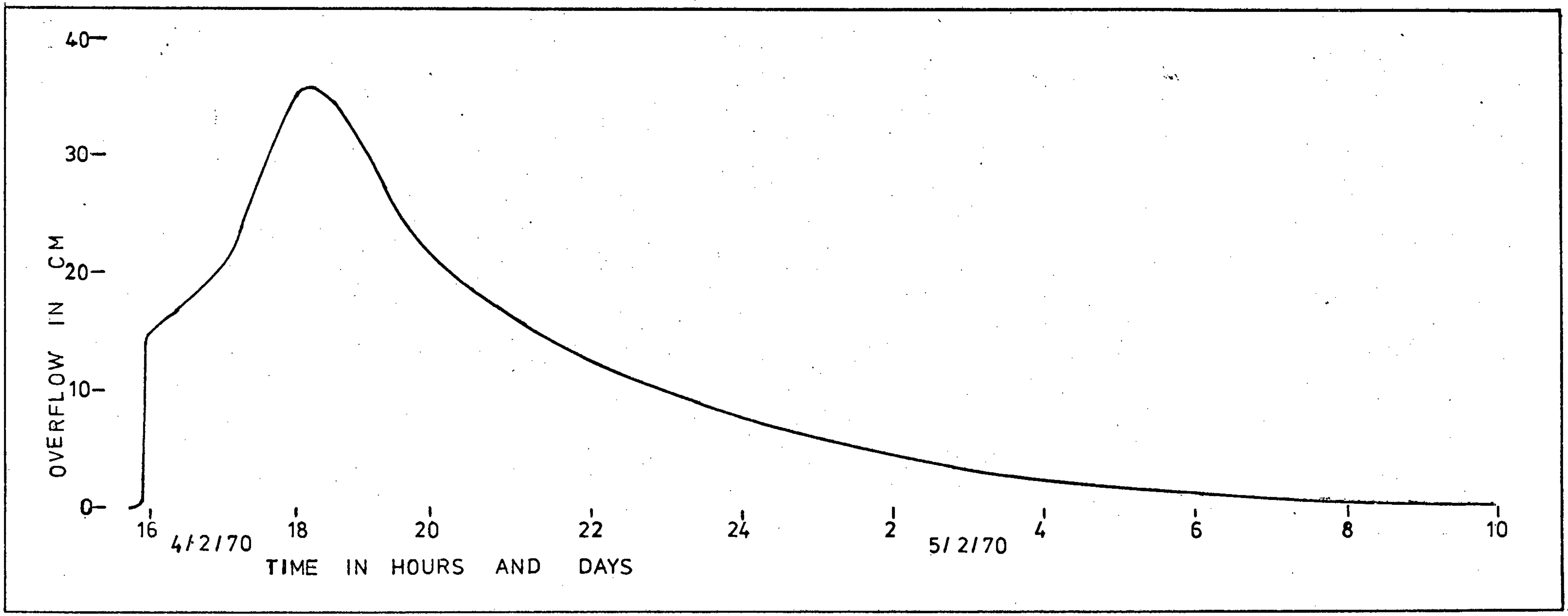


FIG.96 - GRAPH OF FLOW OVER CREST OF WEIR ON 4/2/70 AND 5/2/70; MARYDALE COMMONAGE, N.W.CAPE PROVINCE.

trees. The total area under irrigation was surveyed, and calculated to be 11,838 ha. The total volume of ground-water used to irrigate this area, was calculated from the average depth of water required to maintain growth in this area, according to figures supplied by the Department of Agricultural Technical Services (personal communication) for feed crops and fruit trees. The figures were approximately 1 200 mm and 600 mm per year respectively. The total volume of ground-water used for irrigation was therefore, 107 400 m^3 per year.

11.2.2.13.2 MUNICIPALITY OF MARYDALE

Statistics of the volume pumped by the municipality of Marydale have been available since pumping started in 1964. During the first full year of use (1965) 16 360 m^3 were pumped. The consumption increased steadily to 31 360 m^3 during 1969. Although the population of Marydale remained static, the consumption thus very nearly doubled in four years. From 1969 to 1972 the consumption has remained approximately constant.

11.2.2.14 UNDERGROUND STORAGE

The volume of ground-water stored in the alluvium in the dam basin and the poort must be large. During a rainless period of three months (1/7/69 to 30/9/69) 9 000 m^3 were pumped by the municipality into their reservoir. After good precipitation during April 1969, the rainfall was below normal during May and June, so that the ground-water rest level was probably in equilibrium at the beginning of July. During the three months of withdrawal the rest level dropped by 0,113 m. If it is assumed that the underground inflow and outflow were in equilibrium, this drop was caused by the pumping out of 9 000 m^3 of ground-water. The recoverable ground-water, or effective storage at this level was therefore, 80 400 m^3 per meter of drawdown. The average thickness of saturated alluvium in the dam basin and poort, was calculated as approximately 5,0 m. If the effective storage capacity remains constant over this thickness, the total volume of recoverable ground-water stored in this basin is of the order of 0,4 x $10^6 m^3$. If there was no inflow during the three months, and subsurface outflow was normal, the total volume of water discharged was 84 x $10^3 m^3$. The total volume of recoverable ground-water is then 3,7 x $10^6 m^3$. The total volume of water stored in the alluvium as calculated from the volume of saturated alluvium (105 x $10^6 m^3$) and the storage coefficient (four per cent) is 4,2 x $10^6 m^3$. This figure agrees very well with the second figure above. The volume of recoverable ground-water will probably be between 3,0 and 4,0 x $10^6 m^3$.

11.2.2.15 PERCENTAGE OF PRECIPITATION RECHARGING THE UNDERGROUND WATER RESERVOIR

Because water levels were not measured for long periods over the whole of the catchment area, and the total volume of water stored in the alluvium could not be calculated accurately, the calculations of the percentage of precipitation recharging the underground water reservoir, were based on water level fluctuations at the municipal boreholes, and observation boreholes in the poort and the catchment area.

It was established by means of surveying by theodolite and barometer, and by electrical resistivity depth probes in necks or valleys, that no leakage from the catchment area could have taken place, either at the surface or by subsurface flow, at any place except through the poort at the municipal boreholes.

Calculations of discharge from the catchment area were based on the following:

(i) Estimates of the volume of ground-water withdrawn from the underground reservoir by farmers for domestic use, stock watering, and irrigation.

(ii) The measured discharge of the municipal pumps at the poort.

(iii) The increment or decrement of ground-water storage calculated from the change in ground-water rest level during the period of test.

(iv) Outflow of the spring as measured by the V-notch.

(v) Subsurface outflow as calculated according to the description in Chapter 11.2.2.11.

(vi) Surface flow as estimated from local information about the height of flow, the duration of flow, and the calculated volume of flow over the crest of the dam after it was repaired.

(vii) The difference between the precipitation calculated from the rainfall records and the total of the above, was regarded as the total evapo-transpiration.

Four periods were used for calculations:

(a) During the period 1/1/68 to 31/10/69 the total precipitation in the catchment area was $99{,}76 \times 10^6$ m^3. The rest level at the poort increased by an average of 0,43 m, which was calculated as an increment of 59 100 m^3 in the alluvium of the dam basin. The total volume of water pumped out was calculated as 284 500 m^3, and the subsurface outflow was 550 000 m^3. The outflow of the spring was measured as 23 200 m^3. The water level on 1/1/68 was very near to the normal of the level from November 1964 to December 1967, so that rest level conditions were stable. The percentage of the precipitation which reached the ground-water reservoir was the total of the above, 916 800 m^3 divided by the precipitation, giving a figure of 0,92 per cent. Surface flow during this period amounted to 3,54 per cent of the precipitation and the evapo-transpiration was therefore more than 95 per cent. Seepage into the floor rocks was regarded as negligible, but this is in reality an unknown factor.

(b) Between 12/7/68 and 6/1/69 no nett increment of decrement of storage took place, although water levels and therefore, storage varied considerably between these dates. No surface flow occurred. The total ground-water discharge by pumping, subsurface outflow and flow from the spring, was calculated as 221 000 m^3. Precipitation was $9{,}85 \times 10^6 m^3$. The percentage of recharge was therefore, 2,24 per cent of precipitation.

This percentage might be misleading due to the short period of the test, and the high rainfall during April and May 1968. At Marydale the rainfall during these two months was 352 per cent of the normal rainfall, and ground-water rest levels were almost certainly not yet in equilibrium at the beginning of the test period. This is illustrated by the abnormal rise in the water level of borehole G19070 (Fig. 92) during August 1968, which could not be attributed to rainfall during the test period. Evapotranspiration was more than 97 per cent.

(c) Between 4/5/67 and 6/1/69 there was also no nett increment or decrement of storage. During this period 272 000 m^3 was pumped out, 550 000 m^3 discharged by subsurface flow, and the spring discharged 23 200 m^3, which gives a total volume of discharge of 845 200 m^3. Precipitation was 79,17 x 10^6 m^3, and surface flow was estimated as 3,21 x 10^6 m^3. Ground-water discharge was therefore, 1,07 per cent of rainfall, and surface flow 4,55 per cent. The surface flow occurred as a result of the high rainfall during April-May 1968.

(d) During the period 7/11/64 to 7/4/69 there was a small increment in the storage of ground-water, which was calculated as 31 000 m^3. During the same time the spring discharged 97 500 m^3, 640 600 m^3 was pumped out, and the subsurface discharge was calculated as 1,32 x 10^6 m^3, giving a total discharge of 2,09 x 10^6 m^3. Surface flow during the same period was 4,14 x 10^6 m^3, and the precipitation was 224,3 x 10^6 m^3. The percentage of the precipitation which augmented the ground-water reservoir was, therefore, 0,93 per cent, and surface flow was 1,85 per cent.

11.2.2.16 CONCLUSIONS

(i) The area used for the calculation of recharge covered a variety of geological formations and surface covering which was typical of the "hardeveld" area in the North-western Cape Province, and was large enough to eliminate errors due to purely local conditions.

(ii) Although it was not possible to measure the actual volumes of the discharge by pumping throughout the area, the calculations have a firm basis of average consumption, and can therefore, be regarded as accurate enough over an extended period.

(iii) The precipitation was measured accurately over the greater portion of the catchment area for a period of two years, and by interpolation in certain areas, for the rest of the period. The results were accurate enough for long-term calculations, although sometimes in error for individual showers.

(iv) Surface run-off as estimated in this report is an approximation based on meteorological readings at the Marydale rain gauging station, the flow in the furrow from the spring, depth of flow in the laagte below the dam wall, and estimates by the author, residents of Marydale, and officers of the municipality. This information was correlated with the calculations of flow after completion of the dam wall, and the depth of flow in the laagte caused by this flow. The average surface outflow from this catchment area is probably between two and three per cent. In comparison, Wilke (1961) quoted a figure for run-off of 5,2 per cent of precipitation in the basin of the Zak River, as calculated by the Department of Irrigation for an area with comparable rainfall, situated on the Karoo System.

(v) The subsurface outflow was calculated from the cross-sectional area of saturated alluvium at the narrowest portion of the poort, the average gradient of the rest level at this point, and the average permeability of the alluvium. Because the latter was calculated only near the municipal boreholes it might be in error, due to variations with the depth below surface, and differences across the width of the poort. The figure which was adopted for calculations was, however, based on an estimate of the total flow through the poort, and should be as accurate as can be determined without extended and costly tests.

(vi) In spite of favourable hydrological conditions viz. outcrops of solid rock, topographical relief, shallow water table, high permeability in the alluvium which acted as aquifer, sparse vegetation, a closed catchment, and impounding dams, the ground-water storage was augmented by approximately one per cent of the precipitation, which was an average of 186 mm per year.

(vii) It is obvious that for an increment of only one per cent of the precipitation, the ground-water storage is augmented by an average of less than 2 mm of rainfall. For this catchment area it adds up to a total of 525 000 m^3 per year, which is the safe yield from this area. The present consumption by the municipality and farmers is approximately 160 000 m^3 per year, which is less than a third of the safe yield. The use by the farming community (at present more than 75 per cent of the consumption) is restricted by economic considerations. The supply from this catchment should therefore, be adequate for foreseeable growth of the village of Marydale for a long time in the future.

(viii) Some of the water draining out of the catchment area by subsurface flow, probably reaches the Orange River. In Marydale nearly 50 windmills and power heads were used to pump out water for domestic use and irrigation of small plots. From Draghoender to the north-east more than 30 boreholes and wells draw water from the alluvium in the Marydale Spruit for domestic use, stock watering and irrigation. A large percentage of the subsurface flow through the poort is probably consumed for these purposes. On several farms e.g. Draghoenderputs and Schalksputs, water flows out as springs or marshy areas, so that some of the groundwater is evaporated and transpirated.

12. QUALITY AND TEMPERATURE OF GROUND-WATER

12.1 QUALITY

12.1.1 TRANSVAAL

Very little is known about the quality of ground-water in this area. However, no record exists of any borehole which had to to be abandoned because the water was unsuitable for stock watering. Bond (1947) did not analyse any water from the Archaean Formations in this area.

The specific resistance of water from 30 boreholes in this area was determined by means of a resistivity cell. By comparison with known analyses of water from the same formations in this area, the total dissolved solids (T.D.S.) ranged between 160 and 750 p.p.m.

Partial analyses with the Dearborn Testing Kit was carried out by the author on four samples from boreholes in this area, but it was not extensive enough to determine T.D.S. From the records of the Transvaal Education Department another four partial analyses of water used at schools in this area could be found. The eight analyses are given in Table VII. Six of the boreholes were drilled in granite, and the water from all of them was of good quality, falling within Class A of the S.A.B.S. classification for drinking water (S.A.B.S., 1951). One sample from lava of

TABLE VII. ANALYSES OF BOREHOLE WATER FROM THE ARCHAEAN FORMATIONS IN RUSTENBURG DISTRICT, NORTH-WESTERN TRANSVAAL.

Number of sample	1	2	3	4	5	6	7	8
p.p.m.								
T.D.S.					1116	476	480	374
Cl	24	10	18	100	252	30	37	21
SO_4					21	28	35	5
NO_3					11	4	2	0
HCO_3								317
CO_3								24
F								0,5
$NaHCO_3$								25
Na								42
Ca								15
Mg								50
Phenolpht. Alkal.	4	0	0	0				
Methyl O. Alkal.	290	0	20	260	548			
Total Hardn.	50	164	148	28	720			
Perm. Hardn.					170			0
Temp. Hardn.								245
pH	8,5	7,2	6,8	8,1				8,4

The descriptions of the boreholes are as follows:

1. Welgewaagd 394, borehole near Marico River. Archaean granite.
2. Engeland 862, borehole near house. Archaean gneiss.
3. Belgie 864, borehole next to laagte. Archaean granite.
4. Welgewaagd 394, borehole near Marico River. Lava of Swaziland Syst.
5. Groenvlei 64, borehole at school, drilled in 1948. Sediments of the Swaziland Syst.

6,7, & 8. Van Wykskraal 203, boreholes at school, drilled in 1947, 1945 and 1953 respectively. Archaean granite.

NAMES OF ANALYSTS ARE GIVEN IN THE TEXT

the Swaziland System (No.4) had approximately the same percentages of dissolved solids, except for a high chloride content. The remaining sample, from sediments of the Swaziland System (No.5) had T.D.S. of more than 1 100 p.p.m., mainly due to bicarbonate. In three of the five samples for which the pH-value was determined, it was more than eight, with appreciable soda-alkalinity.

Most of the water from this area can be classified with the soda-carbonate water of the Archaean Granite of the Northern Transvaal, according to the classification by Bond (1947).

12.1.2 CAPE PROVINCE

According to Bond (1947) water from the whole of the area under discussion falls under the highly mineralised chloride-sulphate water. Sixteen analyses are given by him (Table No.3, p.33) from boreholes and wells in the Namaqualand, Kenhardt and Gordonia Districts. Except for the borehole at Springbok, which was drilled in quartzite of the Kheis System, all of the boreholes had very high T.D.S. This was the only borehole in which the water was suitable for human consumption, according to the S.A.B.S. classification. In eleven boreholes the sulphate content was above the permissible maximum, and in eleven out of fourteen analyses the flourine content was too high. Nitrate was determined in twelve samples, and in ten of them it was above the permissible maximum. The majority of these waters did not derive their high nitrate content from surface pollution, but from high nitrification in arid regions, according to Bond (1947).

Analyses of water from a total of 54 boreholes, wells, and springs are given in Tables VIII, IX and X. Most of the analyses were done by the Chemical Services Division of the Department of Agriculture. The analyses at Marydale were done by the Industrial Consulting Laboratories, Cape Town; and the analyses at Pofadder by J.Muller, Buitengracht St., Cape Town.

In most cases water was selected for analysis because of some deviation in taste or quality from the ordinary, so that the analyses given here probably represent some of the more unusual types of ground-water.

In Table VIII eighteen analyses of water from boreholes drilled in granite, gneiss and pegmatite in Gordonia, Namaqualand, Kenhardt, Calvinia and Prieska Districts are given. In Table IX analyses of ten boreholes which were drilled in fracture-zones are given, and ten boreholes drilled on the Pofadder Commonage, nine of then in weathered gneiss and the other in an east-west striking fracture-zone. In Table X analyses are given for three samples of ground-water from alluvium and Tertiary deposists ; four from the quartzitic sediments of the Kheis System ; four from schist and amphibolite, probably altered lava ; four from the Dwyka Series overlying the Archaean formations, and two from springs.

TABLE VIII. ANALYSES OF BOREHOLE WATER FROM GRANITE, GNEISS AND PEGMATITE, NORTH-WESTERN CAPE PROVINCE

Number of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
pH	7,0	7,2	7,6	6,95	8,05	7,4	7,2	8,0	7,9	7,9	7,6	7,7	7,8	8,6	7,5	7,5	7,0	6,8
p.p.m.																		
T.D.S.	13522	5180	4319	1976	2054	3496	6701	26928	2364	4809	9369	6890	6600	871	1667	2059	7301	13358
Na	3484	1316	1300	290	394	967	1760	7055	566	1125	2400	1921	920	163	129	382	1944	3558
K						31	62	61	6	17	42	18	64	28				
SO_4	880	932	452	240	379	1146	1621	3674	517	1297	1835	2036	961	427	384	364	2049	3916
NO_3	0	59	0	43	119	17	3	50	1	155	174	81	34	31	0	0	0	22
NO_2													1	0	0	0	0	
SiO_2								53	52	29	23	32	30	42				
F	3,9	3,4	3,1	2,0	2,5	5,4	4,2	5,5	6,0	3,0	2,5	4,5	0,7	13,0	5,0	6,0	3,6	4,5
Cl	7526	2226	2175	932	702	750	2329	13384	337	1491	3834	2112	3444	46	369	725	2439	4636
CO_3	195	113	111	96	150									24				
Perm.Hard.	4388	1444	795	1080	698	16	1146	7100	0	1050	2200	850		220	640	600	1500	3221
Temp.Hard.	195	113	111	96	150	720	800	351	790	439	439	460		180	260	420	258	224
Ca	773	377	93	229	235	104	245	1231	104	277	529	273	741	36	280	136	389	397
Mg	570	133	163	139	71	63	228	1011	47	158	264	156	578	75	49	166	197	555
HCO_3						439	488	214	787	268	268	281	259	220	317	512		

Description of boreholes:

1. Nachas, Namaqualand. Well in gneiss.
2. Paulsevlei, Calvinia. Borehole in gneiss.
3. Suurwater, Namaqualand. Borehole in gneiss.
4. Brabees, Namaqualand. Borehole in wind-blown sand and gneiss.
5. Spioenkop, Namaqualand. Deep borehole in gneiss.
6. Steynsput, Kenhardt. Borehole in pegmatite and granite.
7. Steynsput, Kenhardt. Borehole No.32608 in granite and gneiss.
8. Rooipan, Prieska. Borehole No.36547 in granite and gneiss.
9. Latrivier, Kenhardt. Well in river in granite and gneiss.
10. Klaarpraat, Kenhardt. Borehole in gneiss under a cover of Dwyka Series.
11. Angelierspan, Kenhardt. Borehole No.36153 in granite.
12. Sonop, Kenhardt. Borehole No.35670 in gneiss.
13. Blaauwputs, Prieska. Borehole in granitised sediments of the Marydale Series.
14. Trooilapspan, Kenhardt. Borehole in Grey Gneiss.
15. Keimoes Commonage, Gordonia. Borehole on island in gneiss, No.G19177.
16. Keimoes Commonage, Gordonia. Borehole on island in gneiss, No.G19175.
17. ~~Kliphakskeen, Namaqualand. Borehole at house in gneiss.~~
18. Bitterputs, Namaqualand. Borehole in granite in pan.

TABLE IX. ANALYSES OF BOREHOLE WATER FROM FRACTURE-ZONES AND GNEISS, NORTH-WESTERN CAPE PROVINCE.

Number of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
pH	7,5	7,7	7,6	7,2	7,4	7,0	6,9	7,2	7,1	7,4	7,5	7,9	7,4	7,6	7,6	7,7	7,5	7,5	7,4
p.p.m.																			
T.D.S.	6924	5459	2269	1810	1884	3533	6527	2516	6798	1130	495	370	410	305	1002	345	890	430	2670
Na	1677	1372	351	510	535	595	1584	720	1554										
K			14																
SO_4	947	636	427	317	317	838	1741	778	1753	247	47	38	36	18	146	23	128	45	602
NO_3	0	0	124	74	74	86	105	105	158										
SiO_2			23																
F	4,7	6,7	3,0	4,5	4,7	3,5	3,0	3,6	3,8	4,7	3,3	4,7	3,8	3,4	3,9	3,2	2,3	3,2	4,1
Cl	3479	2645	710	561	604	1278	2315	866	2556	298	142	71	69	50	230	64	312	92	957
CO_3	60	229																	
Perm.Hard.	2499	1577	700	80	70	1622	1911	550	2175	336	134	16	72	22	362	38	408	108	1137
Temp.Hard.	60	229	480	330	340	159	155	220	250	262	214	210	230	210	222	230	210	212	265
Ca	609	287	229	120	120	385	401	198	551	174	95	47	80	62	209	63	211	99	375
Mg	202	264	82	26	26	186	238	67	255	39	26	26	25	19	14	26	22	17	112
HCO_3			293	403	415			268	305										
Total Hard.										598	348	226	302	232	582	268	618	320	1402

Description of boreholes:

1. Koamsvlei, Namaqualand. Well on north-striking fracture-zone.
2. Witputs, Namaqualand. Borehole on inclined fracture-zone.
3. Longsiekvlei, Kenhardt. Boreholes No.18979 on fracture-zone.
4. Keimoes Commonage. Borehole G19173 on west-striking fracture-zone. Strong supply.
5. Keimoes Commonage. Borehole G19174, very strong supply, on fracture-zone.
6. Lekkerdrink, Namaqualand. Borehole on north-striking fracture-zone.
7. Humites, Namaqualand. Borehole on north-striking fracture-zone.
8. Vergenoeg, Kenhardt. Borehole in west-striking fracture-zone.
9. Witkoppies, Kenhardt. Borehole No.32123 in NNE-striking fracture-zone.
10. Pofadder Commonage, Kenhardt. Borehole at Hotel.
11. Pofadder Commonage, Kenhardt. Borehole in Location.
12. Pofadder Commonage, Kenhardt. Borehole on west-striking fracture-zone, west of Location.
13. Pofadder Commonage, Kenhardt. Borehole at Boys Hostel.
14. Pofadder Commonage, Kenhardt. Borehole at High School.
15. Pofadder Commonage, Kenhardt. Borehole at Power Station.
16. Pofadder Commonage, Kenhardt. Borehole at Hospital.
17. Pofadder Commonage, Kenhardt. Borehole at Outspan.
18. Pofadder Commonage, Kenhardt. Borehole at Coloured School.
19. Pofadder Commonage, Kenhardt. Borehole at Police Station.

NAMES OF ANALYSTS ARE GIVEN IN THE TEXT

TABLE X. ANALYSES OF BOREHOLE WATER FROM DIFFERENT FORMATIONS AND HORIZONS IN THE NORTH-WESTERN CAPE PROVINCE

Number of sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
pH	6,8	7,7	7,8	6,9	7,1	8,2	7,6	7,5	7,9	7,7	7,4	8,1	8,0	7,4	7,5	7,9	3,0
p.p.m.																	
T.D.S.	2635	752	1190	560	1740	2328	9354	6911	2813	5161	2210	10050	4982	1161	968	1100	2275
Na	674		309	132	314	427	3004	1798	603	1424		2608	952	222	220		
K						27	139	20	5	43		10	6				
Ca	417		46	25	154	132	321	353	148	260	401	553	489	98	62		180
Mg	134		49	36	109	142	552	154	104	268		231	79	83	64		
SO_4	203	64	182	72	411	472	2954	1872	493	1681		2484	2598	274	214		1867
NO_3	0			0	0	93	74	161	81	50		167	50	0	30		
SiO_2			71			46	42	28	44	22		32	29				
F	1,6	1,3		1,4	1,6	2,0	6,5	4,5	5,5	2,2		2,0	4,5	1,0	1,4		
Cl	1420	172	320	269	618	639	4189	2237	763	1988	610	3781	604	383	288	300	227
CO_3	76			24	129												Free acid as H_2SO_4 = 743mgm/1
Perm.Hard.	833	64	319	190	687	400	2505	1200	250	1570	728	2150	1300	343	173	392	
Temp.Hard.	76	285	210	24	129	650	570	451	960	255		161	220	243	248		
HCO_3		171				397	695	275	586	311		98	134	296	302		

Description of boreholes:

1. Beenbreek, Namaqualand. Borehole in Koa Valley in Tertiary deposits.
2. Marydale Commonage, Prieska. Borehole in alluvium in poort.
3. Marydale Commonage, Prieska. Borehole in alluvium below dam.
4. Aggeneys, Namaqualand. Borehole in quartzite of the Kheis System in poort.
5. Aggeneys South, Namaqualand. Borehole in quartzitic sediments of the Kheis System.
6. Brakboschpoort, Prieska. Borehole in quartzite of the Kaaien Series.
7. Gifkloof, Kenhardt. Borehole in quartzite of the Kaaien Series.
8. Klaarpraat, Kenhardt. Well in amphibolite.
9. Witklip, Kenhardt. Borehole in amphibolite.
10. Vryheid, Kenhardt. Borehole in schist and amphibolite.
11. Marydale village, Prieska. Borehole in amphibolite.
12. Bosbult, Kenhardt. Borehole in Dwyka Tillite and granite.
13. Diemansput, Kenhardt. Borehole in Dwyka Tillite and granite.
14. Loeriesfontein, Calvinia. Borehole in White Band of the Dwyka Series.
15. Loeriesfontein, Calvinia. Borehole in White Band of the Dwyka Series.
16. Marydale Commonage, Prieska. Perennial Spring below dam.
17. Aggeneys, Namaqualand. Small spring in mountain.

NAMES OF ANALYSTS ARE GIVEN IN THE TEXT

It was impossible to identify the water from the different formations according to their compositions, because there is a large amount of overlap in all of the items analysed. The formations must have contributed only a small proportion of the dissolved solids, most of the salts coming into solution from the overlying soil, alluvium, calcrete, and cover of Dwyka Series.

From the Tables VIII to X the following tentative conclusions can be made:

(i) None of the samples analysed yielded water conforming to the standards of the A Classification of the S.A.B.S. (1951). Only one sample complied with the standards for Class B, because of the high flourine content of the other samples. If the standard adopted by the Department of Water Affairs in South West Africa, viz, 2,0 p.p.m. of flourine, is used, eight of the samples were suitable for domestic use. The T.D.S. were too high for Class B in 33 of the samples, SO_4 in 25 samples, and NO_3 in 25 out of the 39 samples for which this value was determined.

(ii) According to the S.A.B.S. (1951) standards, 96 per cent of the samples analysed were too highly mineralised for human consumption due too high flourine content, 64 per cent due to nitrate content, 61 per cent due to high T.D.S., and 48 per cent due to sulphate content. If the standards applicable in South West Africa are applied, nearly fifteen per cent of the water analysed can be used for human consumption. All the boreholes in Pofadder, which have been used for the past 40 years and more, are unsuitable due to the high flourine content.

(iii) All the samples from fracture-zones had a high flourine content of 3,0 to 6,7 p.p.m. Except for one sample (Table IX, No.2) they are suitable for stock watering according to the standards used in South West Africa. In 60 per cent the sulphate is too high for domestic use, and in 70 per cent the nitrate.

(iv) Except for the deep borehole in the Koa Valley, with high sodium chloride content, all the samples from alluvium (including the spring at Marydale) were suitable for human consumption according to South West African standards. This was also true for the two boreholes in the White Band of the Dwyka Series.

(v) Although the quartzitic sediments of the Kheis System usually yield water of potable quality, very high mineralisation has been recorded e.g. No.7 in Table X. The borehole is situated in a large laagte, and it is reported that, in spite of the high mineralisation, sheep and goats prefer this water to others in this area. It is interesting that potassium in water from the quartzitic sediments is higher than in water from most of the other formations in the area.

(vi) All the samples from amphibolite had more than the permissible T.D.S., flourine, and nitrate for human consumption. Except for one sample, which was just below the permissible maximum, the sulphate content was also too high.

(vii) Although in 40 out of 50 samples, calcium was in excess of magnesium, the ratio Ca : Mg varied between 14,9 and 0,48 in granite and gneiss. Only in the fracture-zones it was always higher than one.

(viii) The small spring issuing on the slope of the Aggeneys Mountain was remarkable for the high percentage of free sulphuric acid. It issued along a shear zone within 100 m of another small spring with potable water.

(ix) Water from the granite and gneiss, which was sampled over the whole of the North-western Cape Province, had the widest range of dissolved solids, from the potable water according to South West African standards, (No.4 of Table VIII), to the highly saline No.8. The more saline samples were from boreholes at pans or vloers.

(x) Because of the low rainfall, and the very small recharge of 2 mm per year or less, an attempt to classify ground-water quality according to areas with increasing average annual rainfall as in Chapter 8.2.2.3 to 8.2.2.6 , was unsuccessful. The topographical relief, and resultant evapo-transpiration had a much greater effect on the quality of the water than the rainfall or the geological formation.

12.2 TEMPERATURE

No systematic recording of the temperature of borehole water was done in the North-western Transvaal. In the North-western Cape Province an attempt was made to measure the ground-water temperature with ordinary mercury thermometers. Where boreholes were equipped with windmills, it was usually impossible to get an accurate reading, due to the small volume of water pumped out and usually a long pipe-line on the surface, which the owner was not prepared to disconnect. The result was very few reliable readings.

At a later stage a maximum and minimum thermometer was lowered into boreholes where possible, to record the temperature below the ground-water rest level. Again, the number of boreholes in which this was possible, was very limited.

Temperatures in boreholes varied between 19,4°C in shale of the Karoo System at a depth of 15 m at Loeriesfontein, Calvinia District, and 27,8°C at a depth of 105 m in a boreholes in granite below shale and dolerite of the Karoo System at Mier, north of Upington.

In the rocks of the Karoo System and the Kaaien Series, the majority of the temperatures measured varied between 21 and 22°C for depths of 15 to 50 m. Where higher temperatures (up to 24°C) were measured at comparable depths e.g. at Brandvlei, Calvinia District, boreholes were situated in pans or vloers, and a relatively high percentage of the rock from the boreholes, was dolerite.

Water from shallow boreholes at depths of 12 to 15 m in Prieska village, had temperatures of 24 to 25°C. The perennial spring in the Prieska River, which issue from alluvium on Dwyka tillite, had a constant temperature throughout the year of 25,3 to 25,7°C. It is interesting that the ground temperatures measured at a depth of 1,2 m at the meteorological station of the Weather Bureau at Prieska, varied between 15,5 and 27,1°C. Maximum average precipitation occurred during February to April, when ground temperatures are near to their peak. This probably accounted for the high temperature of ground-water at shallow depths in this valley.

The temperatures of two other springs were measured:

(i) Riemvasmaak Reserve, Gordonia District. A weak spring issues along a fracture-zone crossing the Molopo River. The temperature was 37,2°C.

(ii) Warmbad Noord, Kenhardt District. A spring issues in the valley of the Orange River on a well-developed fracture-zone with secondary quartz, epidote and breccia. The temperature was 45,0°C. These temperatures indicate deep circulation of the ground-water before issuing at these points. The temperature of the water from the borehole on Hellem, Kenhardt District, which was drilled on a fracture-zone, is also high, being 25,6°C at a depth of 54 m below the surface.

13. DISCUSSION OF RESULTS

Before 1952 hardly any attempt had been made to collect and correlate hydrological and geological data of the Archaean Formations in the North-western Transvaal; and only localised areas were investigated in the North-western Cape Province. The hydrological information in this thesis has been derived from field-work by the author and his colleagues, and from the records of the Department of Water Affairs and the Weather Bureau. The conclusions reached or assertions made, must be attributed solely to the author. The two areas investigated differ widely with regard to climate and topography, but have similar geological and hydrological characteristics.

13.1 LOCATION AND AREA

In the North-western Transvaal the area covered by Archaean rocks is relatively small and homogeneous, covering 4 400 km^2 with low relief and few rock outcrops. The area of similar rocks in the North-western Cape Province is more than fifteen times as large, with a large variety of topographical features, and high relief. Rock outcrops are more numerous, but large areas are covered by soil, wind-blown sand, or calcrete. In both areas perennial rivers are found, which rise far outside the areas of investigation. The area in the North-western Transvaal was investigated during the years 1952 to 1957, and most of the data were collected during this period. Data for the North-western Cape Province were collected principally during the period 1958 to 1971. Older data from both areas were used, when it could be collected and checked for accuracy.

13.2 PHYSIOGRAPHY

The area in the North-western Transvaal has a low relief of 155 m, between 885 and 1 040 m above m.s.l., whereas the relief is approximately ten times as high in the North-western Cape Province. The topographical features in the former area were formed during the post-African Cycle, and in the latter area they range from the Gondwana Cycle to the post-African (King, 1967). The lower reaches of the valley of the Orange River probably pre-dated deposition of the Dwyka Series of the Karoo System.

In neither area is the drainage well-developed, due to the featureless nature of practically the whole of the area in the North-western Transvaal, and large portions in the North-western Cape Province. Run-off therefore accounts for only a very small percentage of the precipitation in both areas. Sites for dams, except for small earthen dams, are scarce.

The whole area in the Transvaal is thickly covered by large trees, bush, and grass, so that transpiration must account for a large percentage of the precipitation. In the Cape Province the vegetal covering is sparse, and consists largely of xerophytic plants. In both areas the fact that most of the rain falls during the summer, enhances the effect of transpiration by plants before the infiltrating water can reach the ground-water reservoir.

The average annual rainfall over the whole area in the North-western Transvaal is 526 mm, varying between an average of 671 mm in the south-east, to 417 mm in the north-west. More than 80 per cent of the rain falls during the summer half-year, and the reliability of the yearly rainfall is more than 80 per cent. This means that precipitation from year to year differs by less than 20 per cent from the above averages over the whole of the area. Because of the permanent vegetal cover, depth of soil, reliability of amount and distribution of rainfall over the whole area, the annual ratio of precipitation to infiltration probably remains more or less constant. The depth of precipitation which percolates down to the ground-water reservoir must, however, be small, probably no more than 5 to 10 mm per annum.

The average annual rainfall in the North-western Cape Province is 176 mm, ranging between averages of 53 mm and 343 mm. The average rainfall is therefore, only one-third of that in Transvaal, and the averages for different portions of the area, cover a much wider range. Precipitation is more evenly distributed during the summer and winter half-years, the percentage of summer rainfall decreasing towards the west and south-west. The reliability of the rainfall is very much less than in the Transvaal, being the lowest recorded in the whole of the Republic of South Africa (Climate of South Africa, 1960). Percentages of 5 and 312 per cent of normal rainfall have been recorded. The low rainfall and extreme variability means that the ratio between precipitation and infiltration varies between wide limits. The depth of precipitation which percolates down to the ground-water reservoir, must be less than in the Transvaal, and probably varies between averages of 0 and 3 mm per annum. The sparse vegetation, however, causes sparse population, and ground-water is more readily available in large portions of the area than in the Transvaal.

13.3 GEOLOGY

There is a large degree of similarity in the statigraphic columns of the two areas for the Precambrian Formations up to the post-Waterberg intrusives. Although no direct correlation was possible, it is probable that the Kheis System is of comparable age to the Swaziland System, the Soetlief Formation to the Dominion Reef System, the Matsap Formation to the Waterberg System, and the Transvaal System being the same succession in both areas. Unfortunately there is almost a total absence of outcrops of the Swaziland System in this part of the Transvaal, so that no subdivisions can be made as in the Kheis System in the Cape Province. Lithologically the formations in the two areas show a strong similarity.

Granitic and gneissic rocks form the bulk of the rock-types in both areas. A large percentage of these rocks was formed by granitisation of sediments, but intrusive and mobilised granite of different ages are also found.

In both areas Tertiary to Recent deposits reach thicknesses of more than 60 m, and cover large areas. Where this cover is not too thick it aids infiltration, but where the thickness is more than 30 m before the ground-water rest level is reached, percolating water hardly, if ever, reaches the ground-water reservoir.

In this part of the Transvaal the geological structure is almost totally obscured by the cover of Tertiary and Recent deposits, except for the broad outlines of a dome, and the folding and faulting in the younger formations along its rim. The structure in the floor rocks beneath the universal cover of younger deposits, was of hydrological importance only in so far as ground-water occurred in cracks and joints in the rock, or where dykes acted as aquifuges. In the Cape Province folding of different ages could be observed in several different directions over large portions of the area. Faulting and shearing played a large part in the movement and concentration of ground-water, but dykes are of lesser importance. Structure is therefore hydrologically of prime importance in this area.

Age determinations were done on most of the Archaean rocks. The Swaziland System seems to be older than the Kheis System, and the Dominion Reef System than the Soetlief Formation, but theyare, nevertheless, of comparable ages. The post-Swaziland Granite is comparable in age to the Geelbeksdam Granite. It is not clear whether the Archaean Granite of the North-western Transvaal differs appreciably in age from the Gaberone Pluton, but the former is probably pre-Dominion Reef. This is deduced from its dome-like occurrence, with the Dominion Reef forming the rim of the dome, and apparently overlying it. The Bushveld igneous Complex is of comparable age to the Vioolsdrift Granite, and the Pilanesberg Dyke Swarm to pegmatite minerals from Namaqualand. The 1 000 m.y. old orogenic belt in the Cape Province does not have a parallel in the Transvaal.

13.4 PREVIOUS INVESTIGATIONS

The results of 65 boreholes selected by geophysicists prior to 1952 in the North-western Transvaal did not differ much from the results of the total of 879 boreholes drilled up to this year, of which records could be traced. The total of 35 per cent of successful boreholes was much lower than the 50 per cent of success in 234 boreholes of which Frommurze (1937) collected the records prior to 1936. After 1952 the percentage of successful borehole sites selected by geophysical surveys were, however, appreciably better. No reports of geophysical investigations prior to 1952 could be traced, except for borehole site selections on individual farms.

In the North-western Cape Province reports were compiled by several geologists prior to 1958, in which the hydrology of certain areas, or certain aspects of hydrology, were discussed. Reports on the hydrology of regions bounding the area under discussion, were drawn up by Wilke in 1961, and Kok in 1963. The importance of secondary structures and the depth of weathering, were stressed. Vegter (1953) discussed geophysical methods of borehole selection and different types of aquifers, but several of his conclusions do not hold water, according to more recent data. According to Kok (1963), results of drilling were more fovourable in the southern portion of South West Africa than in the North-western Cape Province. This can possibly be explained by less intensive drilling in the former area, due to the large areas of individual farms, and the lack of intensive development. The percentage of successful boreholes recorded by Frommurze (1937) is, for the same reason, higher than the results of subsequent recorders.

13.5 GROUND-WATER INVESTIGATIONS

The farmers in both areas, and the villages in the North-western Cape Province which are not situated on the banks of the Orange

River, are totally dependant on ground-water for all their requirements. Water from dams can only be used for very short periods after occasional rains, except for single larger dams or excavation dams, e.g. the Rooiberg Dam near Kenhardt, and the gatdam on Lerato described in the text.

In the North-western Transvaal all the borehole sites, and in the North-western Cape Province a large percentage of them, had to be selected by geophysical means, because geological evidence was inadequate. Although use was made of several different geophysical techniques, the final siting of boreholes were usually based on electrical resistivity or electromagnetic readings. Due to the almost total lack of geological evidence, lack of topographical relief, thick vegetal covering, and depth to the groundwater rest level, more geophysical investigation per unit of surface area had to be done in the North-western Transvaal than in the North-western Cape Province. From the electrical resistivity depth probes taken at existing boreholes, the resistivities associated with different rock-types could be tabulated. Unfortunately there is a wide range of overlap, e.g. apparent resistivity of less than 100 ohm m may be due to weathered granite, weathered sediments or weathered lava of the Swaziland System, or to semi-weathered granite. In the North-western Cape Province conditions were less homogeneous, and no attempt at correlation could be made.

The results from electromagnetic surveys were disappointing in areas with a thick cover of alluvium and deep ground-water rest level. New instruments and techniques have enhanced the value of this method, but too little work has been done to date in the North-western Transvaal and North-western Cape Province to evaluate the possibilities of this instrument.

13.5.1 SWAZILAND SYSTEM

Because almost no outcrops were found, the distribution of this system was deduced from vegetation, magnetic and electrical resistivity surveys, and borehole records. The Swaziland System was composed principally of quartzitic sediments and metamorphosed lava, with subordinate shale, schist, and calcareous rocks. The hydrological properties of these rocks were due to secondary structures and weathering, and were similar in all the rock-types. The Swaziland System was, therefore, treated as a hydrological unit, with the depth of weathering as primary control.

Only 32 per cent of a total of 549 boreholes was successful. More than 90 per cent of the water was struck between depths of 30 and 90 m, and rest levels in nearly 96 per cent of the boreholes were shallower than 60 m. Most of the supplies were struck within 10 m of the depth of weathering. The highest percentage of successsful boreholes was found where apparent resistivities at the rest level were between 50 and 80 ohm m. The quartzitic sediments yielded the highest percentage of successful boreholes.

Other aids to successful siting of boreholes were dykes, a cover of calcrete, drainage lines or pans, and deep weathering deduced from the vegetation. Practically all successful supplies were struck at a shallower depth than 73 m.

13.5.2 KHEIS SYSTEM

This system is divided into (i) the Marydale Series, consisting of metamorphosed acid to basic lava, quartzitic and calcareous sediments, and gneissic granitised sediments; (ii) the Kaaien Series, consisting of quartzite, quartzitic schist, and granitised sediments usually with a gneissic character; (iii) the Wilgenhout Drift Series, consisting principally of reddish arenaceous sediments, schist, and lava. The hydrological properties of these rocks differ widely, and they are discussed seperately.

13.5.2.1 MARYDALE SERIES

Of a total of 54 boreholes in the gneissic rocks 57 per cent were successful, with an average yield of 3,8 m^3/h. In more than 75 per cent of the boreholes water was struck shallower than 75 m, and rest levels in these boreholes were shallower than 57 m. Most of the water was struck in secondary structures below the depth of weathering. Most of the successful boreholes were situated in laagtes near dams.

Only nineteen boreholes could be traced in the volcanics, of which 47 per cent were successful. Ground-water was usually found in the weathered lava at slightly shallower depths than in the gneissic rocks. Rest levels were appreciably shallower, probably due to the more clayey weathering of the volcanics.

Fourteen boreholes were drilled in schist of the Marydale Series, and only 29 per cent were successful, with an average yield of 0,45 m^3/h. Water was struck at a greater depth, and rest levels were deeper than in the formations discussed above.

13.5.2.2 KAAIEN SERIES

The quartzitic sediments of the Kaaien and Marydale Series are probably the best aquifers in this area. A total of 640 boreholes was analysed, and 46 per cent were successful. This percentage is lower than in some of the formations with a localised distribution, but decidedly higher than the average for the whole area. Water was struck shallower than 90 m in 78 per cent of the boreholes, and deeper than 120 m in 6,6 per cent. Rest levels were shallower than 60 m in 88 per cent of the boreholes. In 67 per cent water was struck in secondary structures below the depth of weathering. Where the apparent resistivity was less than 40 ohm m all the boreholes were successful, and the average yield was 7,1 m^3/h. Up to apparent resistivities of 400 ohm m more than 70 per cent of the boreholes were successful.

In 216 boreholes drilled in the granitised sediments, the percentage of successful boreholes was almost identical to that in the quartzitic sediments viz. 45 per cent, but the yields were slightly lower. Water was struck shallower than 75 m in more than 92 per cent, and rest levels were shallower than 60 m in 94 per cent, of the boreholes. A higher percentage of the boreholes than in the quartzitic sediments yielded water shallower than the depth of weathering viz. 39 per cent.

13.5.2.3 WILGENHOUT DRIFT SERIES

Only eight boreholes drilled near the Orange River could be analysed. Of these 62 per cent were successful, with an average yield of 5,0 m^3/h. Water was struck at an average depth of 47 m, and the average rest level was 33 m.

Of the total of 951 boreholes in the Kheis System which was analysed, 45 per cent were successful, compared to 32 per cent of the 549 boreholes drilled in the Swaziland System in Transvaal. The average yield of the former was also much higher than the latter. The average depth at which water was struck, and the average rest level, did not differ much in these formations, except for the volcanics of the Kheis System, in which these depths were shallower. In contrast to the Swaziland System a large percentage of the boreholes yielded water from open secondary structures below the depth of weathering, and this may account for the difference in the percentage of successful boreholes. The Kheis System was deformed intensely by successive cycles of orogeny, and the preponderance of dynamic over chemical weathering, opened up the secondary structures in the predominantly arenaceous sediments. Topographical relief and sparse vegetation aided accumulation of surface water in dams and pans, and facilitated infiltration.

The electrical resistivity apparatus was used more successfully for the locating of borehole sites with economic supplies in the quartzitic sediments of the Kheis System, than in the Swaziland System.

13.5.3 DOMINION REEF SYSTEM

This system consists of arenaceous sediments and basic and acid lavas, the latter being principally quartz-porphyry. The distribution of these lithological units was not always identical, perhaps due to folding. Outcrops were too fragmentary to reach a conclusion.

Only 30 per cent of the 60 boreholes in this formation were successful, and 17 per cent had an economic yield. This low percentage is probably due to the very shallow weathering in most of the rocks. In nearly 90 per cent of the boreholes water was struck shallower than 60 m, and nearly 94 per cent of the rest levels were shallower than this depth. The water was, therefore, usually struck in unconfined aquifers, but in 59 per cent of the boreholes the water was struck slightly deeper than the depth of weathering. From the results of resistivity depth probes the best results were obtained where apparent resistivity at the ground-water rest level varied between 80 and 120 ohm m.

13.5.4 SOETLIEF FORMATION

The Soetlief Formation has a wider distribution in the North-western Cape Province than the Dominion Reef System in the North-western Transvaal. It consists like the latter, of arenaceous sediments at the base, andesitic lava and acid lava (mostly quartz-porphyry and felsite) with subordinate sediments in the higher horizons.

The percentage of successful boreholes in the 79 of which data could be collected, was remarkably high viz. more than 90 per cent, and the average yield was also very high. In more than 70 per cent of the boreholes water was struck shallower than 30 m, and in nearly 96 per cent the rest levels were shallower than 23 m. The most successful boreholes were drilled where the apparent resistivity at the rest level was less than 100 ohm m.

The Soetlief Formation is, therefore, an exceptionally good aquifer, in contrast to the Dominion Reef System in the Transvaal. This is largely due to the favourable topographical position of its largest outcrop area, west of the Doornberg Range with large laagtes crossing it, a relatively thin cover of porous calcrete, a virtual absence of chemical weathering, and impenetrable lava below the weathered zone, which effectively dammed the water at shallow depths. In the other large outcrop area in the Kuip Hills, conditions were also very favourable along the Ongers River.

13.5.5 GRANITE AND GNEISS IN THE NORTH-WESTERN TRANSVAAL

In the Transvaal the older granite occurs in a single compact area between the Marico and Crocodile Rivers. It is usually coarse-grained and light-coloured, grading into a darker-coloured finer-grained gneiss.

Of 930 boreholes drilled in this formation, nearly 38 per cent were successful, and 28 per cent had an economic yield. Of the boreholes with an economic yield, 39 per cent yielded 4,5 m^3/h or more. Most of the boreholes yielded water before a depth of 75 m was reached, but the average weathering was much shallower. Water was often struck in cracks or joints, less than 21 per cent of the boreholes yielding water in the weathered rock. Nearly 25 per cent yielded water more than 18 m below the depth of weathering.

Nearly 86 per cent of the rest levels were between 15 and 60 m below the surface. It was deduced that there is leakage, between the basins of weathering, so that the conditions approach a universal water table in this area. The rest levels were sometimes below the depth of weathering, and the cracks, joints, and other secondary structures must therefore, have a large enough storage capacity to accomodate infiltrating water.

The results of electrical resistivity measurements were inconclusive, except that a greater percentage of successful boreholes were drilled where the granite was well-weathered and the apparent resistivity at the rest level less than 100 ohm m. However, fair results were still obtained for apparent resistivities up to 200 and 300 ohm m. From borehole logging an optimum value both for yield and percentage of successful boreholes was found at specific resistances of 100 to 300 ohm m. Topography played an important role in the results of boreholes, the percentage of successful boreholes near laagtes or rivers, and pans, being more than twice that of boreholes situated away from them. Surface covering and vegetation did not play a large role. It was found that boreholes drilled in granite near to the contact of a dyke, which could be traced by magnetic surveys, had a higher percentage of success than elsewhere, other conditions being equal.

13.5.6 GRANITE AND GNEISS IN THE NORTH-WESTERN CAPE PROVINCE

Although a large percentage of the granite and gneiss has an isotopic age of approximately one thousand million years, this age is due to the last major orogeny, and the rocks were principally derived by granitisation from sediments of the Kheis System. These rocks were found over the whole of the area under discussion, with more or less homogeneous hydrological properties, although large differences were found in lithology, grain size, and colour, and in granitic or gneissic characteristics.

13.5.6.1 GEELBEKSDAM GRANITE

A total of 73 boreholes were analysed, of which 59 per cent were successful, with a high percentage yielding more than 4,5 m^3/h. Water was struck at a shallow depth, in 95 per cent of the boreholes shallower than 60 m. Rest levels were shallower than 45 m in 92 per cent of them. The highest yields and percentage of successful boreholes were found where the apparent resistivity at the rest level was less than 200 ohm m. This granite is a much better aquifer than the Archaean granite in the Transvaal, mostly due to its favourable topographical position and coarse grain, with the resultant deep weathering.

13.5.6.2 GREY GNEISS

The 2 314 boreholes drilled in Grey Gneiss were divided into four groups according to the average annual rainfall in the areas in which they were drilled. There is a decided increase in yield and percentage of successful boreholes with increase of rainfall. The percentage of successful boreholes increased from 22 per cent in areas with an average annual rainfall of less than 100 mm to 40 per cent where this rainfall was more than 200 mm. The greatest difference was between areas with average annual rainfall of 100 - 150 mm (26 per cent) and 150 - 200 mm (38 per cent). The percentage of boreholes yielding more than

4,5 m^3/h increased from 4 to 8 per cent. The percentage of boreholes yielding water shallower than 90 m increased from 77 to 97 per cent, and shallower than 60 m from 49 to 85 per cent. The percentage of boreholes with rest level shallower than 60 m increased from 63 to 95 per cent. In all the groups the depth at which water was struck and the rest levels were shallower for successful boreholes than for the total number of boreholes. This was probably largely due to the more favourable topographical positions of successful boreholes as regards relief and recharge of ground-water. As could be expected, the percentage of boreholes yielding water from cracks and joints more than 30 m below the rest level, decreased from 23 per cent for the low rainfall group, to 8 per cent for the group with average annual rainfall of 150 - 200 mm. The percentage of boreholes striking water within 6 m of the depth of weathering increased from 23 to 29 per cent, and the percentage striking water within 12 m shallower and 18 m deeper than the depth of weathering, from 42 to 58 per cent.

The percentage of successful boreholes was less than 30 for the total number of 2 314 boreholes drilled in Grey Gneiss. This is very much lower than in the Geelbeksdam Granite, and lower than in the Archaean Granite in the Transvaal. In the areas where the average annual rainfall was higher than 150 mm, the results were better than in the North-western Transvaal. These results indicate a progressively higher recharge of ground-water with increase of rainfall, although, as will be shown later, it was only one per cent of the precipitation in areas with average annual rainfall of 150 - 200 mm.

13.5.6.3 GRANITE AND GNEISS UNDER COVER

In the North-western Cape Province water was struck in granite and gneiss which were covered by wind-blown sand, calcrete, or sediments of the Dwyka Series of the Karoo System.

In boreholes with a cover of sediments of the Dwyka Series, more than 40 per cent of the boreholes were successful, and 9 per cent yielded more than 4,5 m^3/h. This was better than any results from the four groups of boreholes drilled in the Grey Gneiss; and it was found that the Dwyka Sereis-granite contact was a good aquifer. The highest percentage of successful boreholes were drilled where the granite contact was at a depth of 45 to 90 m. In 50 per cent of the boreholes water was struck shallower than 45 m in the sediments of the Karoo System, and in 82 per cent shallower than 75 m. Rest levels in 72 per cent of the boreholes were shallower than 45 m. In nearly 50 per cent of the boreholes water was struck more than 12 m below the rest level. This high percentage was due to the confining effect of the clayey sediments of the Dwyka Series. The latter percentage is almost identical to the results from the Grey Gneiss in areas with average annual rainfall of less than 100 mm, but the depth at which water was struck, and the rest levels, are much shallower than in the latter.

Where wind-blown sand covered the granite to a depth of 6 to 9 m, more than 60 per cent of the boreholes were successful. Where the sand cover was more than 33 m thick, no borehole was successful. Where the granite and gneiss were covered by calcrete of 3 to 24 m in thickness, 44 per cent of the boreholes were successful. For a thicker cover, the percentage dropped by almost a half. The effect of a cover of calcrete is almost identical to that in the North-western Transvaal, and the effect of wind-blown sand can be compared to the even better results of a cover of reddish sandy loam in the North-western Transvaal (Fig. 49).

13.5.6.4 DYKES IN GRANITE AND GNEISS

Although dykes were scarce, they had a decided effect on the movement of ground-water. Of 27 boreholes drilled near dykes 70 per cent were successful; and only at the contacts of adamellite dykes was no water found.

13.5.6.5 ANALYSES OF GEOPHYSICAL SURVEYS

The average yield of boreholes was more than 2 m^3/h, and the percentage of successful boreholes 65, where the apparent resistivity at the rest level was between 20 and 280 ohm m. For apparent resistivities between 20 and 160 ohm m, the respective figures are higher viz. 2,2 m^3/h and 71 per cent. Under a cover of sediments of the Dwyka Series, apparent resistivities are lower, and the highest average yields and percentage of successful boreholes were obtained for apparent resisitivities of less than 50 ohm m.

Electro-magnetic surveys by means of the linear method coupled with resistivity surveys, promised good results, but the amount of work done to date by this method, was too little to warrant conclusions about its efficiency in the North-western Cape Province.

13.5.7 YOUNGER INTRUSIVES

The granite of the Gaberone Pluton was only slightly sheared, and most of the water was struck shallower than the depth of weathering, or within 3 m of it. In the case of successful boreholes the percentage was 77. Only 42 per cent of the boreholes were successful, and only 29 per cent yielded an economic supply. In 93 per cent of the successful boreholes water was struck shallower than 60 m, and the rest levels in 70 per cent of the boreholes were less than 12 m shallower than the depths at which water was struck.

Where the apparent resistivity at the ground-water rest level was between 20 and 80 ohm m, more than 50 per cent of the boreholes were successful, and the method of electrical resisitvity depth probes could be applied successfully for the selection of boreholes sites.

There was not much difference in the results from the Archaean

Granite and the Gaberone Granite in the North-western Transvaal, except for the shallower depth at which water was struck in the latter, due to lesser development of joints and cracks. In the case of the Gaberone Granite there was also a pronounced peak in yield and percentage of successful boreholes for apparent resistivities between 20 and 90 ohm m.

Dykes associated with the Gaberone Pluton and the Pilanesberg, were aquifuges and acted as barriers to the flow of ground-water. Good supplies were obtained in boreholes near dykes, especially on the side towards which they dipped.

The adamellite in the North-western Cape Province is practically an aquiclude, only 6 per cent of a total of 68 boreholes being successful. The highest yield of 1,54 m^3/h was obtained in a borehole with a shallow rest level, near the Orange River.

In contrast 69 per cent of the sixteen boreholes drilled in pegmatite to depths below the ground-water rest level, were successful. The depth at which water was struck and the rest levels were nearly the same as in the adamellite.

Dykes in the Soetlief Formation and the sediments of the Kheis System acted as barriers to the flow of underground water. Sixteen boreholes near to dykes could be traced. Fifteen of them were successful, and yields were unusually high. It can therefore, be concluded that in both areas dykes are a valuable aid to the selection of borehole sites, but care must be taken to determine the contacts as accurately as possible, as well as the dip.

13.5.8 FRACTURE-ZONES

In the Transvaal the fracture-zones cemented by secondary quartz act as barriers to the flow of underground water. No successful boreholes were drilled on them, and results of boreholes drilled near to them were poor. The only fracture-zones that yielded good supplies occurred in sediments of the Swaziland System, and were not cemented by secondary quartz.

In the North-western Cape Province a large number of fracture-zones could be traced, usually from surface indications, or where they were covered by younger formations, by geophysical means. These linear structures were of several different ages, and some of them were cemented by secondary quartz so that they acted as aquifuges. An attempt was made to analyse linear structures according to the numbers occurring in each direction of strike, but differences were not large enough to reach significant conclusions. The percentages of successful boreholes in the different strike directions were also too small to determine a specific trend. Some fracture-zones change in direction of strike or dip, or both, along their lengths.

The value of fracture-zones as aquifers lies in the free movement of ground-water along them, so that adequate supplies can be withdrawn from an otherwise poor aquifer. Their storage capacity is small but water is drawn from the less permeable formations along the length and depth of the zone, which may reach depths of several hundred metres, and lengths of several kilometres.

Of a total of 157 boreholes drilled in fracture-zones in the North-western Cape Province 47 per cent were successful. If the number of boreholes which were stopped before the ground-water rest level was reached, and the number which were drilled into solid rock above this level, are subtracted from the total, 63 per cent of the remaining 123 boreholes were successful. Seventeen per cent of these boreholes yielded more than 4,5 m^3/h, which is more than twice the percentage of boreholes with such yields in Grey Gneiss where the average annual rainfall is 150 - 200 mm. These figures illustrate the high permeability of fracture-zones. The depths at which water was struck did not differ much from the average for Grey Gneiss in the North-weatern Cape Province. Fracture-zones are generally permeable to the same depth as cracks and joints in the granite and gneiss.

13.5.9 RECHARGE OF GROUND-WATER

No percentages of recharge have been determined in the North-western Transvaal. The percentage of the precipitation reaching the ground-water reservoir is probably of the order of one per cent.

Evapotranspiration must be high, and it is probable that there is a balance between transpiration by the cover of vegetation, and the amount of precipitation. It was concluded that the drying up or weakening of boreholes was probably due to dewatering of a very localised area, and not to lowering of the rest level in the whole of the area under discussion. Discharge by pumping can probably be increased three or more times by correct siting of boreholes and controlled pumping rates, without permanent dewatering of the aquifers.

In the eastern portion of the area in the North-western Cape Province, the recharge is probably between one and two per cent of the precipitation, and lowering of the rest level, and drying up of boreholes are purely local phenomena. In the sand-covered areas of the Bushmanland Plateau to the west of Kenhardt, recharge must be practically nil, and much of the water now being pumped from boreholes must be regarded as fossil water.

In an area near Marydale village, a test was made to determine the recharge from rainfall. A catchment area of 282 km^2 draining through a narrow poort, was investigated. The average annual rainfall was 185 mm and the geology and topography were fairly representative of the area. Rainfall was measured at ten gauges, and isohyets were drawn, so that the total amount of rainfall for specific periods could be calculated. Pumping tests were carried out to determine the permeability in the aquifer, and depths to the ground-water rest level were measured in a large number of boreholes and wells. The gradient of the rest level was determined from these results in the catchment area, and in the poort. More than 400 depth probes were done and more than 20 boreholes drilled to determine the thickness of the aquifer. Discharge by pumping and surface outflow were measured or calculated for the whole catchment area. The outflow of a perennial spring was measured for several years, until it stopped flowing. Data was collected over a total period of nine years. It could be determined that subsurface outflow from the catchment area could only take place through the poort, and this outflow was calculated. From the sum of these figures, the percentage of the precipitation recharging the ground-water reservoir was calculated. It amounted to very nearly one per cent, as derived from calculations for different periods varying between 21 months and four and a half years. This means that an average of less than 2 mm of the precipitation annually augments the underground storage. The total recharge for the catchment area is then $5 \times 10^5 m^3$ per year, which is regarded as the safe yield. At present the consumption in the catchment area plus the consumption of the village of Marydale amount to $1,6 \times 10^5 m^3$ per year, or less than one-third of the safe yield.

13.5.10 QUALITY AND TEMPERATURE

Most of the ground-water in the North-western Transvaal can be classified with the soda-carbonate water of the Archaean Granite in the Northern Transvaal, according to the classification of Bond (1947). All the supplies were suitable for stock watering, and of a total of 38 samples tested, all were suitable for human consumption, the majority falling within Class A of the S.A.B.S. classification for drinking water (S.A.B.S.,1951).

In the North-western Cape Province the quality of most of the samples was unsuitable for human consumption due to high T.D.S., sulphate, nitrate, and in the majority of the samples which were analysed, too high a fluorine content. Of a total of 70 samples from this area, which were described by Bond or collected by the author, none conformed to Class A of the S.A.B.S. classification, and only two to Class B. If the standards used in South West Africa are applied (permissible flourine content 2 p.p.m.), nine boreholes could be used for domestic purposes. However, almost 70 per cent of the 70 boreholes, wells and springs were used for domestic purposes, on certain farms almost exclusively for decades. Nearly half of the boreholes and wells yielded water which was unsuitable for stock watering according to the standards used in South West Africa. It was not possible to identify the water from different formations according to their composition. The topographical relief, and evapo-transpiration in this arid region had a much greater effect on the quality of the water, than the amount of rainfall or the geological formation from which it was pumped. All the ground-water belong to the highly mineralised chloride-sulphate water according to Bond (1947).

Only a small number of temperatures were measured in the North-western Cape Province. Where rest levels were shallow, temperatures depended to a large extent on the surface temperatures at the time and place of infiltration. Warm and hot springs issued along fracture-zones where the circulation of the ground-water was deep.

14. SUMMARY

An area of 4 400 km^2 in the North-western Transvaal is compared to an area of 75 000 km^2 in the North-western Cape Province with similar Archaean rock-types. The physiography and geology of the areas are described in some detail. A review of previous ground-water investigations are given, and a resumé of aspects of hydrological research with special reference to procedures in the locating of borehole sites and underground water reservoirs. In the above areas, where geological outcrops were scarce, the importance of geophysical methods of boreholes selection is stressed. A total of more than 5 200 borehole results were analysed with respect to the area and the geological formation in which they were drilled.

In these Archaean Formations the percentage of successful boreholes ranged from 29 per cent in the Grey Gneiss to 45 per cent in the Kheis System, except for the adamellite with 6 per cent and the Soetlief Lava with 90 per cent of successful boreholes. In spite of much lower rainfall, results were slightly better in the North-western Cape Province than in the Transvaal, except for a few outstanding formations. Water was found from the surface to a depth of 213 m, but the majority of boreholes yielded water shallower than 120 m. Rest levels varied betweeen the surface and 171 m, with the majority shallower than 90 m. Fracture-zones were better than average aquifers in the North-western

Cape Province, but aquifuges in the Transvaal. The recharge of ground-water in the arid North-western Cape Province was calculated as one per cent of precipitation for an area with average annual rainfall of 150 - 200 mm. In other portions of this area it ranges between nought and two per cent. In both areas the ground-water potential has not been fully developed. Criteria for better results in the selection of borehole sites are given, and approximate safe yields for specific areas were calculated. The quality of ground-water was good throughout the area investigated in the North-western Transvaal. In the North-western Cape Province most of the supplies were unsuitable for human consumption according to accepted standards.

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